Consultative
Committee for
Space Data Systems

RECOMMENDATION FOR SPACE
DATA SYSTEMS STANDARDS

RADIO FREQUENCY AND MODULATION SYSTEMS

PART 1
EARTH STATIONS AND SPACECRAFT

CCSDS 401.0-B

BLUE BOOK

AUTHORITY

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These Recommendations reflect the consensus technical agreement of the following member agencies of the Consultative Committee for Space Data Systems (CCSDS):

- o British National Space Centre (BNSC)/United Kingdom.
- o Canadian Space Agency (CSA)/Canada.
- o Centre National D'Etudes Spatiales (CNES)/France.
- o Deutsche Forschungsanstalt fuer Luft-und Raumfahrt e.V (DLR)/West Germany.
- o European Space Agency (ESA)/Europe.
- o Indian Space Research Organization (ISRO)/India.
- o Instituto de Pesquisas Espaciais (INPE)/Brazil.
- o National Aeronautics and Space Administration (NASA)/USA.
- o National Space Development Agency of Japan (NASDA)/Japan.

The following observer agencies also concur with these Recommendations:

- o Chinese Academy of Space Technology (CAST)/People's Republic of China.
- o Department of Communications, Communications Research Centre (DOC-CRC)/Canada.
- o Institute of Space and Astronautical Science (ISAS)/Japan.

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STATEMENT OF INTENT

The Consultative Committee for Space Data Systems (CCSDS) is an organization officially established by the management of member space agencies. The Committee meets periodically to address data systems problems that are common to all participants, and to formulate sound technical solutions to these problems. Inasmuch as participation in the CCSDS is completely voluntary, the results of Committee actions are termed RECOMMENDATIONS and are not considered binding on any agency.

These RECOMMENDATIONS are issued by, and represent the consensus of, the CCSDS Plenary body. Agency endorsement of these RECOMMENDATIONS is entirely voluntary. Endorsement, however, indicates the following understandings:

- o Whenever an agency establishes a CCSDS-related STANDARD, this STANDARD will be in accord with the relevant RECOMMENDATION. Establishing such a STANDARD does not preclude other provisions which an agency may develop.

- o Whenever an agency establishes a CCSDS-related STANDARD, the agency will provide other CCSDS member agencies with the following information:

  -- The STANDARD itself.

  -- The anticipated date of initial operational capability.

  -- The anticipated duration of operational service.

- o Specific service arrangements shall be made via memoranda of agreement. Neither these RECOMMENDATIONS nor any ensuing STANDARDS are a substitute for a memorandum of agreement.

No later than five years from its date of issuance, these RECOMMENDATIONS will be reviewed by the CCSDS to determine whether they should: (1) remain in effect without change; (2) be changed to reflect the impact of new technologies, new requirements, or new directions; or (3) be retired or canceled.

FOREWORD

This document, which is a set of technical Recommendations prepared by the Consultative Committee for Space Data Systems (CCSDS), is intended for use by participating space agencies in their development of radio frequency and modulation systems for earth stations and spacecraft.

These Recommendations allow implementing organizations within each agency to proceed coherently with the development of compatible Standards for the flight and ground systems that are within their cognizance. Agency Standards derived from these Recommendations may implement only a subset of the optional features allowed by the Recommendations herein, or may incorporate features not addressed by the Recommendations.

In order to establish a common framework within which the agencies may develop standardized communications services, the CCSDS advocates adoption of a layered systems architecture. These Recommendations pertain to the physical layer of the data system. Within the physical layer, there are additional layers covering the: technical characteristics, policy constraints, and procedural elements relating to communications services provided by the radio frequency and modulation systems. Recommendations contained in this document have been grouped into separate sections representing technical, policy, and procedural matters.

These Recommendations for Radio Frequency and Modulation Systems, Part 1: Earth Stations and Spacecraft, were developed for conventional near-earth and deep space missions having moderate communications requirements. Part 2 will be concerned with data relay satellites and will address the needs of users requiring services not provided by the earth stations covered in this document.

The CCSDS will continue to develop Recommendations for Part 1: Earth Stations and Spacecraft, to ensure that new technology and the present operating environment are reflected. New Recommendations for Part 1, which are developed in the future, will utilize the same format and be designed to be inserted into this book. Holders of this document should make periodic inquiry of the CCSDS Secretariat, at the address shown above, to make sure that their book is fully current.

Through the process of normal evolution, it is expected that expansion, deletion, or modification to this document will be required. Therefore, these Recommendations are subject to CCSDS document management and change control procedures which are defined in Reference [1].

DOCUMENT CONTROL

DOCUMENT	TITLE	DATE	STATUS/REMARKS
CCSDS 401.0 B-1	Recommendations for Space Data System Standards. Radio Frequency and Modulation Systems, Part 1: Earth Stations and Spacecraft, Issue-1	January 1987	Original Issue
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REFERENCES

[1] *Procedures Manual for the Consultative Committee for Space Data Systems*, Issue 1, Consultative Committee for Space Data Systems, August 1985 or later issue.

[2] *Radio Frequency and Modulation Report*, CCSDS 411.0 G-1, June 1990, or latest edition.

[3] *Radio Regulations*, International Telecommunication Union, Geneva, Switzerland, 1982.

[4] *Recommendations and Reports of the CCIR*, 1986 Plenary Assembly, Dubrovnik, Yugoslavia, 1986.

The latest issues of CCSDS documents may be obtained from the CCSDS Secretariat at the address indicated on page i.

CONTENTS

1.0 INTRODUCTION

1.1 PURPOSE

This document recommends standards for radio frequency and modulation systems operated by the Consultative Committee for Space Data Systems (CCSDS) member and observer agencies.

1.2 SCOPE

Recommendations contained in this document, *Radio Frequency and Modulation Systems, Part 1*, focus upon the standardization of RF and modulation systems for earth stations and spacecraft. Part 2, when completed, will comprise Recommendations relating to data relay satellite systems. Unlike the CCSDS *Radio Frequency and Modulation Report*, Reference [2], these Recommendations describe the capabilities, policies, and procedures that the CCSDS agencies believe will be needed in future years. By proposing specific characteristics and attributes for subjects in these categories, the CCSDS hopes that the ensuing designs will be sufficiently similar so as to permit cross-support of one agency's spacecraft by another agency's network.

These Recommendations are complementary to the information contained in the *RF and Modulation Report*. To obtain a complete understanding of an agency's tracking facilities, readers should consult both documents. The *Report* describes the RF and modulation characteristics of spacecraft tracking systems that the CCSDS member and observer agencies are planning for the post-1990 time period. It comprises a multiplicity of tables summarizing the technical characteristics of those systems.

These Recommendations do not provide specific designs. Rather they describe certain capabilities and provide technical characteristics in sufficient detail so that an agency may design compatible equipment. Guidelines are also provided for the use of agencies' RF and modulation systems, as well as, their use of the RF spectrum. Because an ability to provide cross-support implies some standardization of design and operations, certain procedural Recommendations have been included to assist in these areas. Recommendations are assigned to one of three sections depending upon whether their primary focus is technical, policy, or procedural in nature.

These Recommendations are intended to promote an orderly transition to RF and modulation systems that are internationally compatible. The CCSDS believes that this course will not only assure better engineering practices but, also, that it will facilitate international cross-support agreements.

1.3 APPLICABILITY

These Recommendations apply to future implementation of RF and modulation systems. In combination with the *RF and Modulation Report*, Reference [2], this document describes the physical transport system used to carry data to and from spacecraft and earth stations.

1.4 DOCUMENT FORMAT

These introductory remarks are followed by three sections containing technical, policy and procedural Recommendations, respectively. Often, it is not obvious to which section a Recommendation belongs because it may be concerned with more than one area. The decision usually turns upon whether the primary focus is quantitative, directive, or instructive.

Section 2 contains Technical Recommendations. Following the format established in the CCSDS *RF and Modulation Report*, technical Recommendations are subdivided into groups representing the various subsystems. These are:

2.1	*Earth-to-Space Radio Frequency*	2.4	*Telemetry*
2.2	*Telecommand*	2.5	*Radio Metric*
2.3	*Space-to-Earth Radio Frequency*	2.6	*Spacecraft*

Recommendations pertaining to each of these subjects are grouped together for easy accessibility. This approach facilitates cross referencing with the Report. If a reader wishes to determine whether an agency follows a specific CCSDS Recommendation, he need only turn to the corresponding section in the *Report* to determine that agency's capabilities.

Section 3 comprises Policy Recommendations. Because of the requirement for sharing the radio frequency spectrum, it is desirable to establish guidelines to promote its efficient use. Accordingly, these Recommendations are directive in nature and are principally concerned with operational aspects. Specific sections are:

3.1	*Frequency Utilization*	3.4	*Operational Procedures*
3.2	*Power Limitations*	3.5	*Testing Recommendations*
3.3	*Modulation Methods*	3.6	*Spacecraft Systems*

Section 4 holds Procedural Recommendations. Here will be found Recommendations intended to assist agencies with procedures or processes. At this juncture, only one subsection has been identified. This is:

4.1 *Design Tools*

As additional procedural topics are identified, this section will be expanded with appropriate subsections.

Section 5 defines Terms and provides a Glossary for acronyms used in these Recommendations. This section is intended as an aid for readers to facilitate a uniform interpretation of the Recommendations. Two subsections are required:

5.1	*Terminology*	5.2	*Glossary*

Because the Recommendations are designed to be easily removable from this book to facilitate copying, a unique page numbering system has been employed. Recommendation page numbers contain information about the section, subsection, position, mission category, and page number. Thus, Page 2.5.3A-1 tells the reader, in order, that this is: a Technical Recommendation (2), for Radio Metric systems (5), the third in that subsection (3), concerned with Category A missions (A), the first page of that Recommendation (1). This numbering system, is intended to avoid confusion and errors when returning pages to the book by uniquely describing the position of each page in the document.

Unlike other CCSDS Recommendations which focus upon specific topics such as channel coding or SFDUs, this document contains several subjects related to radio frequency and modulation systems. To promote brevity, clarity, and expandability, the authors have adopted a recommendation format which is similar to the one used by the International Telecommunications Union's (ITU) International Radio Consultative Committee (CCIR).

Each Recommendation consists of brief statements and generally requires only one or two pages. Reasons justifying each Recommendation are set forth in clear, crisp sentences. When appropriate, additional information providing the rationale for a Recommendation is included as an annex to this document. This modular format permits inclusion of additional Recommendations as the CCSDS agencies' RF and modulation systems grow and as technology matures.

1.5 DEEP SPACE AND NON-DEEP SPACE

Much of the radio frequency standardization has already been accomplished by the International Telecommunications Union (ITU) and will be found in the Radio Regulations. The provisions contained in the ITU Radio Regulations, as well as applicable CCIR documents, are adopted and incorporated here by reference.

Four *radiocommunication services* are of interest to the CCSDS. In accordance with the ITU definitions these are: the Space Research Service, the Space Operation Service, the Earth Exploration Satellite Service, and the Meteorological Satellite Service.

Within the Space Research Service, a distinction is made between *Deep Space* and *non-Deep Space* spacecraft. Those bands allocated to *Space Research/Deep Space* shall only be used by spacecraft engaged in interplanetary research, whose range exceeds a specified distance.

Earth station - spacecraft distance is important for two reasons. First, certain frequencies are reserved for spacecraft operating in *Deep Space*. Second, the RF and modulation characteristics may be different for the two categories.

Formerly, the Radio Regulations set the *Deep Space* boundary at lunar distance. However, the advent of spacecraft in highly elliptical earth orbits that go beyond lunar distance, or which may be in orbits around the sun-earth libration points, resulted in non-optimum use of the *Deep Space* bands when frequency assignments for these missions were based upon the former definition.

In October 1988, the World Administrative Radio Conference (WARC) ORB-88 revised the boundary for *Deep Space* contained in Article 1 of the ITU Radio Regulations. The new boundary for *Deep Space*, which became effective on 16 March 1990, has been established to be at a distance equal to, or greater than, 2.0 x 106 km.

While the Radio Regulations contain a definition for *Deep Space*, they do not specifically name that zone lying closer to the earth. Thus, there is no internationally recognized term for *non-Deep Space* missions.

Several years ago, the CCSDS recognized the deficiencies with the ITU's lunar distance *Deep Space* boundary. Accordingly, CCSDS members agreed among themselves to establish the *Deep Space* boundary at 2.0×10^6 km whenever that was possible under the then existing Radio Regulations. To avoid confusion with the ITU's definition for *Deep Space*, as well as to simplify the nomenclature for missions at any distance, the CCSDS defined the following mission categories:

Category A	Those missions having an altitude above the earth of less than, 2.0×10^6km.
Category B	Those missions having an altitude above the earth of greater than, or equal to, 2.0×10^6 km.

Figure 1.5-1 pictorially depicts the Category A and B mission regions.

Because this terminology has become well established over the years, and because the ITU has still failed to define that region lying closer to earth than 2.0 x 10^6 km, the CCSDS will continue to use the two Categories to represent the applicability of a Recommendation to a specific class of mission.

Therefore, the letter A or B following the Recommendation number means that the Recommendation applies solely to Category A or Category B missions respectively. If the Recommendation number stands alone, with neither an A or B following, then that Recommendation applies equally to both Category A and Category B missions.

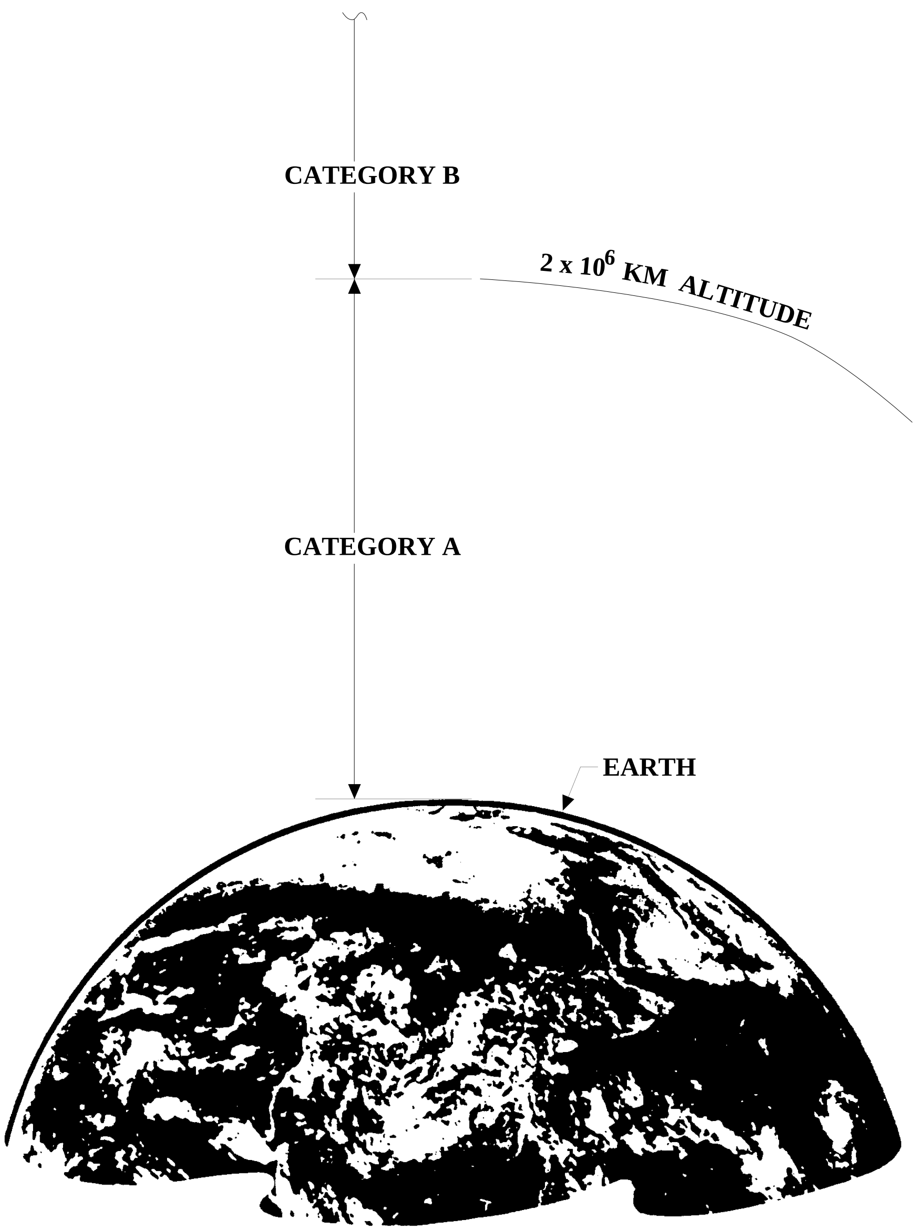


FIGURE 1.5-1. MISSION CATEGORIES

2.0 TECHNICAL RECOMMENDATIONS

Section 2 focuses upon the technical characteristics of RF and modulation systems for earth stations and spacecraft. Each recommended standard delineates a specific capability which the CCSDS agencies believe will be needed in future years. Some suggested standards argue for retaining existing facilities, while others propose developing systems not presently used by any agency. The goal is to set forth recommended standards with which the agencies can create a group of uniform capabilities.

To facilitate the document’s use, this section has been subdivided into six modules, each containing an individual subject:

2.1	*Earth-to-Space Radio Frequency*	2.4	*Telemetry*
2.2	*Telecommand*	2.5	*RadioMetric*
2.3	*Space-to-Earth Radio Frequency*	2.6	*Spacecraft*

Note that these subsections are identical to, and have been arranged in the same order as, those found in the CCSDS Radio Frequency and Modulation Report. However, an additional subsection for spacecraft has been included. Here, one can find those characteristics pertaining to spacecraft radio frequency and modulation systems.

Six summary tables corresponding to the six modules follow these introductory remarks. These tables contain the subject matter of each recommendation, its number, and a summary description. Using these tables, the reader can quickly locate specific recommendations contained in Section2.

EARTH-TO-SPACE RF RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
2.1.1	Phase Modulation	Use with residual carriers.
2.1.2	Circular Polarization	Use on earth-to-space RF links.
2.1.3A	± (1-150) kHz; ± (1-500) kHz	Min Cat A acquisition sweep range at 2 and 7 GHz.
2.1.3B	± (1-300) kHz; ± (1-1000) kHz	Min Cat B acquisition sweep range at 2 and 7 GHz.
2.1.4A	500 Hz/s ≤ 50 kHz/s	Min Cat A acquisition sweep rate range.
2.1.4B	1 Hz/s ≤ 10 kHz/s	Min Cat B acquisition sweep rate range.
2.1.5	Pos Voltage → Pos Phase Shift	Modulator input voltage to carrier phase shift.
2.1.6	10 dB Carrier Suppression	Max carrier suppression resulting from all signals.
2.1.7B	Mod Indices; Data Rates Codes	Constraints from simultaneous service operations.
2.1.8A	Uplink Freq Steps ≤ 100 Hz	Min Cat A earth station transmitter freq resolution.
2.1.8B	Uplink Freq Steps 0.01 ≤ 5 Hz	Min Cat B earth station transmitter freq resolution.

TELECOMMAND RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
2.2.1	Reserved	
2.2.2	8 or 16 kHz, PSK, Sine Wave	Subcarrier frequencies, modulation, and waveform.
2.2.3	NRZ-L, M	Choice of telecommand data waveforms.
2.2.4	$4000/2^n$; $n = 0, 1, 2 \ldots 9$	Range of telecommand bit rates.
2.2.5	$\pm 2 \times 10^{-4} f_{sc}$; $\pm 1 \times 10^{-5}$; $\pm 5 \times 10^{-5}$	Subcarrier frequency offset and stabilities.
2.2.6	$0.98 \leq 1.02$	Symmetry of baseband modulating waveforms.

SPACE-TO-EARTH RF RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
2.3.1	Residual Carriers	Use with low bit rate telemetry systems.
2.3.2	Suppressed Carriers	Use where residual carriers exceed PFD limits.
2.3.3A	± 150 kHz; ± 600 kHz	Min Cat A acquisition sweep range at 2 and 8 GHz.
2.2.3B	± 300 kHz; ± 1 MHz	Min Cat B acquisition sweep range at 2 and 8 GHz.
2.2.4A	100 Hz/s ≤ 420 kHz/s	Min Cat A acquisition sweep rate at 2 and 8 GHz.
2.2.4B	1 Hz/s ≤ 10 kHz/s	Min Cat B acquisition sweep rate at 2 and 8 GHz.
2.3.5	RCP or LCP	Polarization of space-to-earth links.
2.3.6	Pos Voltage → Pos Phase Shift	Modulator input voltage to carrier phase shift.
2.3.7	$\pm 5 \times 10^{-13}$ $(0.2 \leq s \leq 100)$	Min earth station reference frequency stability.
2.3.8	10 dB Carrier Suppression	Max carrier suppression resulting from all signals.

TELEMETRY RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
2.4.1	Reserved	
2.4.2	NRZ-M (DNRZ) Modulation	Use with suppressed carrier systems.
2.4.3	Subcarriers	Use with very low rate residual carrier subsystems.
2.4.4	PSK Modulation	Use with telemetry subcarriers.
2.4.5	Sine Wave; Square Wave	Cat A; Cat B subcarrier waveforms.
2.4.6	$\pm 1 \times 10^{-4} f_{sc}$; $\pm 1 \times 10^{-6}$; $\pm 1 \times 10^{-5}$	Subcarrier frequency offset and stabilities.
2.4.7	NRZ-L; SP-L	Choice of PCM waveforms in resid. carrier systems.
2.4.8	$0.98 \leq 1.02$	Symmetry of baseband modulating waveforms.
2.4.9	64; 125/1000; 275/1000	Min Cat A: Cat B symbol transition densities.
2.4.10	00=0°; 01=90°; 11=180°; 10=270°	Channel coding conventions for QPSK systems.

RADIO METRIC RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
2.5.1A	10 ns	Min Cat A group delay calibration accuracy.
2.5.2A	20 ns	Min Cat A earth station group delay stability in 12h.
2.5.2B	2 ns	Min Cat B earth station group delay stability in 12h.
2.5.3A	± 50 ns	Min Cat A spacecraft group delay stability.
2.5.3B	± 30 ns	Min Cat B spacecraft group delay stability.
2.5.4A	± 0.5 dB (3 kHz ≤ 110 kHz)	Min Cat A ranging transponder bandwidth.
2.5.4B	± 0.5 dB (3 kHz ≤ 1.1 MHz)	Min Cat B ranging transponder bandwidth.
2.5.5A	20 ns	Max Cat A regen. transponder PN code delay change.

SPACECRAFT RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
2.6.1	221/240 Transponder Radio	Freq ratio 2025-2120 MHz to 2200-2300 MHz.
2.6.2	749/880 Transponder Ratio	Freq ratio 7145-7235 MHz to 8400-8500 MHz.
2.6.3A	221/900 Transponder Ratio	Cat A Freq ratio 2025-2110 MHz to 8450-8500 MHz.
2.6.4A	765/240 Transponder Ratio	Cat A Freq ratio 7190-7235 MHz to 2200-2290 MHz.
2.6.5B	221/880 Transponder Ratio	Cat B Freq ratio 2110-2120 MHz to 8400-8450 MHz.
2.6.6B	749/240 Transponder Ratio	Cat B Freq ratio 7145-7190 MHz to 2290-2300 MHz.
2.6.7 to	Reserved for 13-15 GHz and	
2.6.11	32-34 GHz Transponder Ratios	
2.6.12	$15 \leq 45$ Hz; $1 \leq 3$ Hz	Min Cat A; Cat B transponder AGC amplifier BW.

2.1.1 RF CARRIER MODULATION OF THE EARTH-TO-SPACE LINK

The CCSDS,

considering

(a) that most space agencies currently utilize spacecraft receivers employing phase-locked loops;

(b) that conventional phase-locked loop receivers require a residual carrier to operate efficiently;

(c) that phase modulation results in efficient demodulation;

recommends

that CCSDS agencies provide a capability to support phase modulation with a residual carrier for their earth-to-space links.

2.12 POLARIZATION OF EARTH-TO-SPACE LINKS

The CCSDS,

considering

(a) that a linear electric field polarization on links to spacecraft, having nearly omnidirectional antenna patterns, may vary considerably with aspect angle;

(b) that the aspect angle of a near-earth orbiting satellite varies greatly during a pass;

(c) that for satellites having a stable linear polarization in the direction of the earth station (e.g., geostationary satellites with suitable attitude stabilization or satellites using tracking antennas) the propagation effects such as Faraday rotation may cause substantial rotation in the received polarization at lower carrier frequencies;

(d) that automatic correction of rotation in the earth station's polarization adds undesirable complexity to the system;

(e) that most existing earth stations are equipped for RCP and LCP polarization;

recommends

(1) that CCSDS agencies use circular polarization on their earth-to-space RF links for telecommand and ranging;

(2) that payload service links use circular polarization in those cases where TTC is carried out in the payload service band or where on-board antennas are shared with payload functions;

(3) that the earth station be designed to switch between LCP and RCP polarization without causing an interruption of the transmitted carrier exceeding 5 seconds in those cases where changes of polarization are desired.

2.13A TRANSMITTER FREQUENCY SWEEP RANGE ON EARTH-TO-SPACE LINKS, CATEGORY A

The CCSDS,

considering

(a) that the doppler frequency shift on the earth-to-space link, resulting from relative motion between earth stations and Category A spacecraft, can achieve values up to:

± 80 kHz at 2 GHz
± 300 kHz at 7 GHz;

(b) that the rest frequency uncertainties in spacecraft receivers are in the order of:

± 50 kHz at 2 GHz
± 200 kHz at 7 GHz;

(c) that the lock-in frequency range of spacecraft receivers is much smaller than the frequency deviations given in (a) and (b);

(d) that the doppler frequency shift can usually be predicted to an accuracy of better than ± 1 kHz;

(e) that most of the spacecraft receivers have a tracking range up to:

± 150 kHz at 2 GHz
± 500 kHz at 7 GHz;

(f) that the acquisition time should be kept to a minimum;

recommends

that the earth station’s transmitter should have a minimum sweep range capability of at least:

± 1 kHz

and a maximum sweep range capability of:

± 150 kHz at 2 GHz
± 500 kHz at 7 GHz.

2.1.3B TRANSMITTER FREQUENCY SWEEP RANGE ON EARTH-TO-SPACE LINKS, CATEGORY B

The CCSDS,

considering

(a) that the doppler frequency shift on the earth-to-space link, resulting from relative motion between earth stations and category B spacecraft, can achieve values up to:

± 250 kHz at 2 GHz
± 900 kHz at 7 GHz;

(b) that the rest frequency uncertainties in spacecraft receivers are on the order of:

± 1 kHz at 2 GHz
± 4 kHz at 7 GHz;

(c) that the doppler frequency shift can usually be predicted to an accuracy of ± 1 kHz;

(d) that most of the spacecraft receivers have tracking ranges less than or equal to:

± 300 kHz at 2 GHz
± 1 MHz at 7 GHz;

(e) that the lock-in frequency range of spacecraft receivers is much smaller than the frequency deviations given in (a) and (b) above;

(f) that the effect on the radio link, resulting from variation in the columnar charged-particle content, is generally negligible;

(g) that the acquisition time should be kept to a minimum;

recommends

that the earth station’s transmitter should have a minimum sweep range capability of:

± 1 kHz at 2 and 7 GHz

and a maximum sweep range capability of at least:

± 300 kHz at 2 GHz
± 1 MHz at 7 GHz.

2.1.4A TRANSMITTER FREQUENCY SWEEP RATE ON EARTH-TO-SPACE LINKS, CATEGORY A

The CCSDS,

considering

(a) that the rate of change of the doppler frequency shift on the earth-to-space link, resulting from relative motion between earth stations and Category A spacecraft, is smaller than:

3 kHz/s at 2 GHz
10 kHz/s at 7 GHz;

(b) that most of the spacecraft receivers have a phase-locked loop with a bandwidth (2 B_{LO}) in the range 200 Hz to 800 Hz at their threshold;

(c) that the maximum permissible rate of input frequency variation for most types of spacecraft receivers is between 2 kHz/s and 30 kHz/s at their threshold;

(d) that the frequency sweep rate on the earth-to-space link should be chosen such that the total rate of frequency variation, resulting from both the transmitter's sweep rate and the orbital doppler rate, does not unlock the spacecraft's phase-locked loop;

(e) that the acquisition time should be kept to a minimum for each mission phase;

recommends

that the earth station's transmitter should have a minimum frequency sweep rate capability of:

500 Hz/s

and a maximum frequency sweep rate capability of at least:

50 kHz/s.

2.1.4B TRANSMITTER FREQUENCY SWEEP RATE ON EARTH-TO-SPACE LINKS, CATEGORY B

The CCSDS,

considering

(a) that the rate of change of the doppler frequency shift on the earth-to-space link, resulting from relative motion between earth stations and category B spacecraft, is smaller than:

60 Hz/s at 2 GHz
200 Hz/s at 7 GHz;

(b) that most of the spacecraft receivers have a phase-locked loop with a bandwidth (2 B_{LO}) in the range 10 Hz to 100 Hz at their threshold;

(c) that the maximum permissible rate of input frequency variation for this type of spacecraft receiver is between 6 Hz/s and 1 kHz/s at its threshold;

(d) that the maximum permissible rate of input frequency variation for signals above the receiver's threshold can be as much as 10 kHz/s;

(e) that the frequency sweep rate on the earth-to-space link should be chosen such that the total rate of frequency variation, resulting from both the transmitter's sweep rate and the orbital doppler rate, does not unlock the spacecraft's phase-locked loop;

(f) that the acquisition time should be kept to a minimum for each mission phase;

recommends

that the earth station's transmitter should have a minimum frequency sweep rate capability of:

1 Hz/s

and a maximum frequency sweep rate capability of at least:

10 kHz/s.

2.1.5 RELATIONSHIP OF MODULATOR INPUT VOLTAGE TO RESULTANT RF CARRIER PHASE SHIFT

The CCSDS,

considering

that a clear relationship between the modulating signal and the RF carrier's phase is desirable to avoid unnecessary ambiguity problems;

recommends

that a positive-going voltage at the modulator input should result in an advance of the phase of the radio frequency signal.

NOTE:

l. This Recommendation is also filed as Rec. 401 (2.3.6) B-1.

2.1.6 RF CARRIER SUPPRESSION ON EARTH-TO-SPACE LINKS FOR RESIDUAL CARRIER SYSTEMS

The CCSDS,

considering

that high modulation indices may make the residual carrier difficult to detect with a conventional phase-locked loop receiver;

recommends

that CCSDS agencies select modulation indices such that the reduction in carrier power, with respect to the total unmodulated carrier power, does not exceed 10 dB.

NOTE:

1. This Recommendation is also filed as Rec. 401 (2.3.8) B-1.

2.1.7B OPERATIONAL AND EQUIPMENT CONSTRAINTS RESULTING FROM SIMULTANEOUS TELECOMMAND AND RANGING IN RESIDUAL CARRIER SYSTEMS, CATEGORY B

The CCSDS,

considering

(a) that coherent transmissions are generally employed for making range measurements to a Category B mission spacecraft;

(b) that conventional phase locked loop receivers require a residual carrier component to operate properly;

(c) that sufficient power must be reserved to the residual carrier so that the spacecraft receiver can track with an acceptable phase jitter;

(d) that sufficient power must be allocated to the command data channel to obtain the required bit error rate;

(e) that in two-way operation, the noise contained in the transponder's ranging channel bandwidth will be retransmitted to the earth station along with the ranging signal;

(f) that sufficient power must be allocated to the ranging signal to obtain the required accuracy and probability of error;

(g) that some ranging systems permit the simultaneous transmission of several tone frequencies from the earth station and that a proper choice of these frequencies will minimize the cross-modulation and interference to the telecommand signal by the ranging signal;

(h) that transmission of a single, low frequency ranging tone by the earth station may result in interference in the telecommand channel on the spacecraft;

recommends

(1) that the telecommand modulation index shall not be less than 0.2 radians peak;

(2) that the telecommand data bit rate shall not exceed 2000 b/s when simultaneous telecommand and ranging operations are required;

(3) that the earth station's ranging modulation index shall not exceed 1.4 radians peak;

(4) that the telecommand subcarrier's period should be an integer subdivision of the data bits's period;

(5) that for those ranging systems which do not conform with "recommends" (6) below, the telecommand subcarrier's period should be a coherent multiple of the ranging tone's period;

(6) that, where necessary, each and every lower frequency ranging tone be chopped (modulo-2 added) with the highest frequency ranging tone;

2.1.8A MINIMUM EARTH STATION TRANSMITTER FREQUENCY RESOLUTION FOR SPACECRAFT RECEIVER ACQUISITION, CATEGORY A

The CCSDS,

considering

(a) that Category A spacecraft receivers typically have phase-locked loop bandwidths (2 B_{LO}) in the range of 200 to 800 Hz at their thresholds;

(b) that, for spacecraft receivers having a second order phase-locked-loop with the threshold bandwidths shown in (a), the frequency lock-in range is typically 267 to 1067 Hz;

(c) that steps in earth station's transmitter frequency which exceed the spacecraft receiver's lock-in range can result in long acquisition times or complete failure of the spacecraft to acquire the signal;

(d) that some margin should be included to ensure proper acquisition of the earth station's signal by the spacecraft receiver's phase-locked loop;

(e) that the spacecraft's receiver may fail to acquire or remain locked to the earth station's transmitted signal if abrupt phase discontinuities in that signal occur during the acquisition of that signal;

recommends

(1) that the earth station transmitter's frequency be adjustable over its specified operating range in increments (step size) of 100 Hz or less;

(2) that the earth station transmitter's RF phase continuity be maintained at all times during tuning operations, using frequency sweep rates that are in accordance with Recommendation 401 (2.1.4A) B-1, which will ensure that the spacecraft's receiver remains locked following acquisition.

2.1.8B MINIMUM EARTH STATION TRANSMITTER FREQUENCY RESOLUTION FOR SPACECRAFT RECEIVER ACQUISITION, CATEGORY B

The CCSDS,

considering

(a) that Category B spacecraft receivers typically have phase-locked loop bandwidths (2 B_{LO}) in the range of 10 to 100 Hz at their thresholds;

(b) that for spacecraft receivers having a second order phase-locked-loop with the threshold bandwidths shown in (a), the frequency lock-in range is typically 13 to 133 Hz;

(c) that steps in earth station's transmitter frequency which exceed the spacecraft receiver's lock-in range can result in long acquisition times or complete failure of the spacecraft to acquire the signal;

(d) that some margin should be included to ensure proper acquisition of the earth station's signal by the spacecraft receiver's phase-locked loop;

(e) that, with certain Category B missions, it is desirable to continuously tune the earth-to-space link's transmitter frequency to maintain its value, at the spacecraft, at a single, optimal frequency;

(f) that the spacecraft's receiver may fail to acquire or remain locked to the earth station's transmitted signal if abrupt phase discontinuities in that signal occur during the acquisition of that signal;

recommends

(1) that the earth station's transmitter frequency be variable over its specified operating range in increments (step size) which can be adjusted from 0.01 Hz to 5 Hz;

(2) that the earth station transmitter's RF phase continuity be maintained at all times during tuning operations, using frequency sweep rates that are in accordance with Recommendation 401 (2.1.4B) B-1, which will ensure that the spacecraft's receiver remains locked following acquisition.

2.2.2 SUBCARRIERS IN TELECOMMAND SYSTEMS

The CCSDS,

considering

(a) that most space agencies presently utilize either 8 kHz or 16 kHz subcarriers for telecommand transmissions where data rates are less than or equal to 4 kb/s;

(b) that modulation schemes employing subcarriers reduce the interference to the RF carrier loop resulting from data sidebands;

(c) that PSK modulation is the most efficient type of digital modulation because of its bit error performance;

(d) that it is important to limit the occupied bandwidth;

recommends

that CCSDS agencies use a sine wave subcarrier for telecommand, with a frequency of either 8kHz or 16 kHz, which has been PSK modulated.

2.2.3 CHOICE OF WAVEFORMS IN TELECOMMAND LINKS

The CCSDS,

considering

(a) that NRZ-L, -M waveforms result in efficient spectrum utilization;

(b) that present telecommand bit rates are generally less than or equal to 4 kb/s;

(c) that telecommand data sidebands are separated from the carrier by employing a PSK subcarrier;

(d) that NRZ-L waveforms result in very good signal-to-noise performance;

(e) that NRZ-M waveforms avoid ambiguity errors;

recommends

(1) that CCSDS agencies use NRZ-L, -M waveforms with PSK subcarriers for telecommand data;

(2) that due consideration be given to the bit transition density of the telecommand modulation to ensure proper operation of the spacecraft's receiving equipment.

2.2.4 RANGE OF TELECOMMAND BIT RATES

The CCSDS,

considering

(a) that many space agencies utilize PCM-PSK modulation for the telecommand links;

(b) that phase coherency between the PCM signal and the subcarrier facilitates system implementation;

(c) that subcarrier frequencies of either 8 kHz or 16 kHz are commonly used;

(d) that many space agencies have developed, or will develop, equipment using telecommand data rates in the range 8-4000 b/s;

recommends

(1) that CCSDS agencies provide telecommand bit rates in the range $4000/2^n$ b/s, where n = 0, 1, 2,...,9;

(2) that data bit and subcarrier transitions should coincide.

NOTE:

1. A 4000 b/s rate should only be used with a 16 kHz subcarrier and care should be taken to ensure that harmful interactions with other signals do not occur.

2.2.5 TELECOMMAND SUBCARRIER FREQUENCY STABILITY

The CCSDS,

considering

(a) that the present use of subcarriers for modulating the earth-to-space RF links represents a mature technique for both Categories A and B missions and, therefore, is a well settled standard;

(b) that modifications of this standard imply costly changes to space agencies' networks;

recommends

that CCSDS agencies' earth stations be designed to provide telecommand subcarriers with characteristics which are equal to or better than:

Maximum Subcarrier Frequency Offset	$\pm (2 \times 10^{-4}) f_{SC}$;
Minimum Subcarrier Frequency Stability (1 second);	$\pm 1 \times 10^{-5}$
Minimum Subcarrier Frequency Stability (24 hours).	$\pm 5 \times 10^{-5}$

NOTE:

1. f_{SC} = frequency of telecommand subcarrier.

2.2.6 SYMMETRY OF BASEBAND DATA MODULATING WAVEFORMS

The CCSDS,

considering

(a) that the earth station's transmitter power should be used as efficiently as possible;

(b) that undesired spectral components in the earth station's transmitted signal should be minimized;

(c) that time-asymmetry in the modulating waveform results in a DC-component;

(d) that such a DC-component in the modulating waveform results in a data power loss because of AC-coupling in the modulator;

(e) that, in addition to the power loss, time-asymmetry results in matched filter losses;

(f) that the above losses should not exceed 0.1 dB;

(g) that the out-of-band emissions resulting from the time-asymmetry in the modulating waveform can be reduced by additional filtering;

recommends

that, the symmetry of all baseband square wave modulating waveforms should be such that the mark-to-space ratio will lie between 0.98 and 1.02.

NOTE:

1. This Recommendation is also filed as Rec. 401 (2.4.8) B-1 for the space-to-earth link.

2. Where Bi-Phase modulation is utilized, larger baseband signal losses, than are permitted by *considering (f)*, may result.

2.3.1 RESIDUAL CARRIERS FOR LOW RATE TELEMETRY, SPACE-TO-EARTH LINKS

The CCSDS,

considering

(a) that many space agencies own and/or operate earth stations for communication with spacecraft in which they have substantial investments;

(b) that these earth stations contain receiving equipment employing phase-locked loops;

(c) that conventional phase-locked loop receivers require a residual carrier component to operate properly;

(d) that most space agencies use autotrack systems for Category A missions, which need a residual carrier;

recommends

that CCSDS agencies retain residual carrier receiving systems in their earth stations for use with missions having low rate telemetry requirements.

2.3.2 SUPPRESSED CARRIERS FOR HIGH RATE TELEMETRY, SPACE-TO-EARTH LINKS

The CCSDS,

considering

(a) that present technology makes the implementation of suppressed carrier systems practicable;

(b) that a comparison of carrier signal-to-noise ratios in a conventional residual carrier phase-locked loop with those in a suppressed carrier loop shows that the latter provides a substantial advantage over the former, frequently exceeding 10 dB;

(c) that a comparison of data symbol errors occurring in a conventional residual carrier phase-locked loop system with those occurring in a suppressed carrier loop System shows that the latter's performance is no worse, and frequently is better, than that of the former;

(d) that suppressed carrier systems lend themselves to compliance with PFD limits on the earth's surface more readily than do residual carrier systems;

(e) that some space agencies still use autotrack systems for their Category A missions, which need a residual carrier;

recommends

(1) that CCSDS agencies utilize suppressed carrier systems for space-to-earth communications when a residual carrier system would exceed the PFD limits on the earth's surface;

(2) that CCSDS agencies may provide a beacon for autotracking their Category A missions using suppressed carrier modulation.

2.3.3A EARTH STATION RECEIVER ACQUISITION FREQUENCY SWEEP RANGE, CATEGORY A

The CCSDS,

considering

(a) that the space-to-earth link may be operated in either a coherent turnaround mode, or in a one-way mode;

(b) that for the coherent turnaround mode, the doppler frequency shift induced on both the earth-to-space and the space-to-earth links is the major factor to be considered in selecting the frequency sweep range;

(c) that for the one-way mode, both the doppler frequency shift induced on the space-to-earth link and the frequency stability of the spacecraft's oscillator are the major factors to be considered in selecting the frequency sweep range;

(d) that the maximum rate of change of distance between the earth station and Category B spacecraft can reach values of up to 10 km/s;

(e) that the minimum frequency stability found in Category A spacecraft reference frequency oscillators is about $\pm 2 \times 10^{-5}$;

recommends

(1) that CCSDS agencies' earth station receivers be capable of frequency Sweep ranges of at least:

± 150 kHz at 2 GHz
± 600 kHz at 8 GHz

(2) that CCSDS agencies provide a minimum sweep range that is consistent with their ability to predict the doppler frequency shift.

2.3.3B EARTH STATION RECEIVER ACQUISITION FREQUENCY SWEEP RANGE, CATEGORY B

The CCSDS,

considering

(a) that the space-to-earth link may be operated in either a coherent turnaround mode, or in a one-way mode;

(b) that in the coherent turnaround mode, the doppler frequency shift induced on both the earth-to-space and the space-to-earth links is the major factor to be considered in selecting the frequency sweep range;

(c) that the effect on the radio link, resulting from variation in the columnar charged-particle content, is generally negligible;

(d) that the maximum rate of change of distance between the earth station and Category B spacecraft can reach values of up to 35 km/s;

(e) that the minimum frequency stability found in Category B spacecraft reference frequency oscillators is about 1×10^{-6};

recommends

that CCSDS agencies' earth station receivers be capable of frequency sweep ranges of at least:

± 300 kHz at 2 GHz
± 1 MHz at 8 GHz.

2.3.4A EARTH STATION RECEIVER ACQUISITION FREQUENCY SWEEP RATE, CATEGORY A

The CCSDS,

considering

(a) that the space-to-earth link may be operated in either a coherent turn-around mode or in a one-way mode;

(b) that in the coherent turn-around mode, the doppler frequency rates induced on both the earth-to-space and the space-to-earth links are the major factors to be considered in selecting the earth station receiver's frequency sweep rate;

(c) that in the one-way mode, the doppler frequency rate on the space-to-earth link and the earth station receiver's phase locked loop bandwidth (2 B_{LO}), with its resulting maximum permissible input frequency variation, are the major factors to be considered in selecting the sweep rate;

(d) that the rate-of-change of velocity between the earth station and Category A spacecraft can reach values up to 380 m/s^2 at orbital altitudes of 300 km, which results in frequency variation rates of approximately 3 kHz/s at 2 GHz and 10 kHz/s at 8 GHz in the one-way mode (or 6 kHz/s and 20 kHz/s respectively in the coherent turn-around mode);

(e) that the earth station's receivers generally have phase locked loop bandwidths (2 B_{LO}) in the range of 30 Hz to 2 kHz at their threshold;

(f) that, for an acquisition probability of 0.9, the maximum permissible rate of input frequency variation for this type of earth station receiver is between 100 Hz/s and 400 kHz/s at its threshold;

(g) that the earth station receiver's frequency sweep rate plus the spacecraft's doppler frequency rate must not exceed the receiver's ability to achieve phase-locked operation;

(h) that the acquisition time should be kept to a minimum for each mission phase;

recommends

that CCSDS agencies' earth station receivers operating in the 2 and 8 GHz bands should have a minimum frequency sweep rate not exceeding 100 Hz/s and a maximum frequency sweep rate of at least 420 kHz/s.

2.3.4B EARTH STATION RECEIVER ACQUISITION FREQUENCY SWEEP RATE, CATEGORY B

The CCSDS,

considering

(a) that the space-to-earth link may be operated in either a coherent turnaround mode, or in a one-way mode;

(b) that in the coherent turnaround mode, the doppler frequency rates induced on both the earth-to-space and the space-to-earth links are the major factors to be considered in selecting the earth station receiver's frequency sweep rate;

(c) that in the one-way mode, the doppler rate on the space-to-earth link and the earth station receiver's phase-locked loop bandwidth (2 B_{LO}), with its resulting maximum permissible input frequency variation, are the major factors to be considered in selecting the sweep rate;

(d) that the rate of change of velocity between the earth station and category B spacecraft can reach values up to 10 m/s^2;

(e) that the earth station's receivers have phase-locked loop bandwidths (2 B_{LO}) in the range of 1 Hz to 1 kHz at their thresholds;

(f) that typical earth station receivers, operating in the 2 and 8 GHz bands, allow a maximum permissible rate of input frequency variation of between 1 Hz/s and 10 kHz/s;

(g) that the receiver's frequency sweep rate, plus the orbital doppler frequency rate, must not exceed the earth station receiver's ability to achieve phase-locked operation;

(h) that the acquisition time should be kept to a minimum for each mission phase;

(i) that a lower limit for the signal-to-noise ratio in the earth station receiver's phase-locked loop is approximately 8.5 dB;

recommends

that CCSDS agencies' earth station receivers, operating in the 2 and 8 GHz bands, should have a minimum sweep rate not exceeding 1 Hz/s and a maximum sweep rate of at least 10 kHz/s.

2.3.5 POLARIZATION OF SPACE-TO-EARTH LINKS

The CCSDS,

considering

(a) that a linear electric field polarization on links from spacecraft, having nearly omnidirectional antenna patterns, may vary considerably with aspect angle;

(b) that the aspect angle of a near-earth orbiting satellite varies greatly during a pass;

(c) that for satellites having a stable linear polarization in the direction of the earth station (e.g., geostationary satellites with suitable attitude stabilization or satellites using tracking antennas), the propagation effects such as Faraday rotation may cause changes in the received polarization at lower carrier frequencies;

(d) that many earth stations are equipped with polarization diversity receivers;

(e) that many existing spacecraft TTC antenna designs provide circular polarization;

recommends

(1) that CCSDS agencies utilize LCP or RCP polarization for satellite TTC space-to-earth links unless sharing of equipment with payload functions requires a different approach;

(2) that automatic polarization tracking should be used for reception of satellite signals wherever possible;

(3) that polarization diversity reception should be used to meet the required system time constants at earth stations used for Category A missions.

2.3.6 RELATIONSHIP OF MODULATOR INPUT VOLTAGE TO RESULTANT RF CARRIER PHASE SHIFT

The CCSDS,

considering

that a clear relationship between the modulating signal and the RF carrier's phase is desirable to avoid unnecessary ambiguity problems;

recommends

that a positive-going voltage at the modulator input should result in an advance of the phase of the radio frequency signal.

NOTE:

1. This Recommendation is also filed as Rec. 401 (2.1.5) B-1.

2.3.7 EARTH STATION OSCILLATOR REFERENCE FREQUENCY STABILITY

The CCSDS,

considering

(a) that most of the space agencies use a reference frequency standard to which the earth station's receiver and transmitter local oscillators are locked;

(b) that the short term frequency stability of the local oscillator substantially determines the range rate measurement's accuracy for Category A missions;

(c) that the long term frequency stability of the local oscillator substantially determines the range rate measurement's accuracy for Category B missions;

(d) that it is desirable for many missions to determine range rate with an accuracy of 1 mm/s or better;

(e) that the oscillator's frequency shall be sufficiently stable such that its effect upon the range rate measurement's error shall be significantly less than 1 mm/s;

(f) that, in addition to the foregoing, the long term stability of the local oscillator is also determined by the drift permitted in the earth station's clock which should not exceed 10 microseconds per month;

recommends

(1) that the short term frequency stability (Allan Variance) shall be better than $\pm 5 \times 10^{-13}$ for time intervals between 0.2 s and 100 s;

(2) that for Category B missions and for timekeeping, the long term frequency stability shall be better than $\pm 2 \times 10^{-12}$ for any time interval greater than 100 s.

2.3.8 RF CARRIER SUPPRESSION ON SPACE-TO-EARTH LINKS FOR RESIDUAL CARRIER SYSTEMS

The CCSDS,

considering

that high modulation indices may make the residual carrier difficult to detect with a conventional phase-locked loop receiver;

recommends

that CCSDS agencies select modulation indices such that the reduction in carrier power, with respect to the total unmodulated carrier power, does not exceed 10 dB.

NOTE:

1. **This Recommendation is also filed as Rec. 401 (2.1.6) B-1.**

2.4.2 MODULATING PCM WAVEFORMS FOR SUPPRESSED CARRIER SYSTEMS

The CCSDS,

considering

(a) that interaction between data sidebands and their RF carrier causes undesirable performance degradation;

(b) that suppressed carrier modulation schemes eliminate interaction between data sidebands and the RF carrier;

(c) that the necessary bandwidth for a suppressed carrier system with NRZ modulation is less than for a residual carrier system using Manchester or subcarrier modulation schemes;

(d) that the lack of a carrier reference at the demodulator results in a phase ambiguity of 180 degrees in the data;

(e) that this phase ambiguity is unacceptable and must be removed either by providing periodic, recognizable bit patterns for polarity determination, or by using a modulation that is insensitive to polarity;

(f) that DNRZ modulation is insensitive to polarity;

(g) that DNRZ inherently produces doublet errors, but bit pattern polarity determination schemes can result in the loss of entire frames;

(h) that some CCSDS member agencies use DNRZ suppressed carrier modulation in their relay satellites to reduce the necessary bandwidth while preventing data-carrier interaction;

(i) that either NRZ-M or NRZ-S is an acceptable DNRZ modulation scheme;

(j) that NRZ-M is currently in use;

recommends

(1) that suppressed carrier modulation schemes use NRZ-M waveforms;

(2) that in convolutionally encoded systems requiring conversion between NRZ-L and NRZ-M, the conversion from NRZ-L take place before the input to the Viterbi encoder, and the conversion from NRZ-M to NRZ-L take place after the output from the Viterbi decoder in order to maximize performance.

2.4.3 SUBCARRIERS IN LOW BIT RATE RESIDUAL CARRIER TELEMETRY SYSTEMS

The CCSDS,

considering

(a) that at low bit rates, interaction between data sidebands and the residual RF carrier causes a performance degradation;

(b) that subcarrier modulation schemes eliminate interaction between data sidebands and the residual RF carrier;

(c) that some space agencies presently utilize ranging systems whose minor tones are below 20 kHz and whose major tone is 100 kHz, while others are planning to do so in the near future;

(d) that simultaneous ranging and telemetry operation should be possible;

recommends

(l) that CCSDS agencies use subcarriers with their residual carrier systems when transmitting low bit rates;

(2) that the subcarrier be placed between the 20 kHz and 100 kHz ranging tones, or above the 100kHz tone.

2.4.4 PSK MODULATION FOR TELEMETRY SUBCARRIERS

The CCSDS,

considering

(a) that PSK modulation is a very efficient type of digital modulation because of its bit error performance;

(b) that many space agencies presently utilize PSK subcarrier modulation techniques, while others are planning to do so in the near future;

recommends

that CCSDS agencies use PSK subcarrier modulation if a telemetry subcarrier is employed.

2.4.5 TELEMETRY SUBCARRIER WAVEFORMS

The CCSDS,

considering

(a) that space agencies frequently employ subcarriers to separate data sidebands from the RF carriers;

(b) that for Category A missions, it is more important to limit the occupied bandwidth while for Category B missions, it is more important to minimize the susceptibility to in-band interference;

(c) that it is easier to generate square wave subcarriers;

recommends

(1) that for Category A mission telemetry transmissions, CCSDS agencies use sine wave subcarriers when they are modulated in the PSK mode;

(2) that for Category B mission telemetry transmissions, CCSDS agencies use square wave subcarriers when they are modulated in the PSK mode.

2.4.6 TELEMETRY SUBCARRIER FREQUENCY STABILITY

The CCSDS,

considering

(a) that the present use of subcarriers for modulating the space-to-earth RF links represents a mature technique for both Categories A and B missions and, therefore, is a well settled standard;

(b) that modifications of this standard imply costly changes to space agencies' networks;

recommends

that spacecraft radio frequency subsystems generating telemetry subcarriers be designed with characteristics equal to or better than:

Maximum Subcarrier Frequency Offset	$\pm (1 \times 10^{-4}) f_{SC}$
Minimum Subcarrier Frequency Stability (short term)	$\pm 1 \times 10^{-6}$
Minimum Subcarrier Frequency Stability (long term)	$\pm 1 \times 10^{-5}$

NOTES:

1. **f_{SC} = frequency of telemetry subcarrier.**

2. **Short term time intervals are less than or equal, 100 times the subcarrier's waveform period.**

2.4.7 CHOICE OF PCM WAVEFORMS IN RESIDUAL CARRIER TELEMETRY SYSTEMS

The CCSDS,

considering

(a) that NRZ waveforms rely entirely on data transitions for symbol clock recovery, and this recovery becomes problematical unless an adequate transition density can be guaranteed;

(b) that due to the presence of the mid-bit transitions, Split Phase (SP) waveforms provide better properties for bridging extended periods of identical symbols after initial acquisition;

(c) that convolutionally encoded data have sufficient data transitions to ensure symbol clock recovery in accordance with the CCSDS recommended standards;

(d) that with coherent PSK subcarrier modulation, it is possible by adequate hardware implementation to bridge extended periods of identical symbols even when NRZ waveforms are used;

(e) that NRZ waveforms without a subcarrier have a non-zero spectral density at the RF carrier;

(f) that coherent PSK subcarrier modulated by NRZ data and using an integer subcarrier frequency to symbol rate ratio, as well as SP waveforms, have zero spectral density at the RF carrier;

(g) that the ambiguity which is peculiar to NRZ-L and SP-L waveforms can be removed by adequate steps;

(h) that use of NRZ-M and NRZ-S waveforms results in errors occurring in pairs;

(i) that it is desirable to prevent unnecessary decoder node switching by frame synchronization prior to convolutional decoding (particularly true for concatenated convolutional Reed-Solomon coding);

(j) that to promote standardization, it is undesirable to increase the number of options unnecessarily, and that for any proposed scheme, those already implemented by space agencies should be considered first;

recommends

(1) that for modulation schemes which use a subcarrier, the subcarrier to bit rate ratio should be an integer;

(2) that in cases where a subcarrier is employed, NRZ-L should be used;

(3) that for direct modulation schemes having a residual carrier, only Split Phase - Level (SP-L) waveforms should be used;

(4) that ambiguity resolution should be provided.

2.4.8 SYMMETRY OF BASEBAND DATA MODULATING WAVEFORMS

The CCSDS,

considering

(a) that the spacecraft's transmitter power should be used as efficiently as possible;

(b) that undesired spectral components in the spacecraft's transmitted signal should be minimized;

(c) that time-asymmetry in the modulating waveform results in a DC-component;

(d) that such a DC-component in the modulating waveform results in a data power loss because of AC-coupling in the modulator;

(e) that, in addition to the power loss, time-asymmetry results in matched filter losses;

(f) that the above losses should not exceed 0.1 dB;

(g) that the out-of-band emissions resulting from the time-asymmetry in the modulating waveform can be reduced by additional filtering;

recommends

that, the symmetry of all baseband square wave modulating waveforms should be such that the mark-to-space ratio will lie between 0.98 and 1.02.

NOTE:

1. **This Recommendation is also filed as Rec. 401 (2.2.6) B-1 for the earth-to-space link.**

2. **Where Bi-Phase modulation is utilized, larger baseband signal losses, than are permitted by *considering (f)*, may result.**

2.4.9 MINIMUM MODULATED SYMBOL TRANSITION DENSITY ON THE SPACE-TO-EARTH LINK

The CCSDS,

considering

(a) that symbol clock recovery systems usually extract the clock's frequency from the received symbol transitions;

(b) that a large imbalance between ones and zeros in the data stream could result in a bit-error-rate degradation in the symbol detection process;

(c) that NRZ waveforms are widely used in standard modulation systems;

(d) that NRZ waveforms require sufficient symbol transitions for symbol clock recovery;

(e) that the tracking system loop bandwidth is usually less than, or equal to, one percent of the symbol rate;

(f) that, for Category A, the specified degradation in bit error rate, due to symbol sync error, is usually less than 0.3 dB;

(g) that, for Category B, the specified degradation in bit error rate, due to symbol sync error, is usually less than 0.1 dB;

recommends

(1) that the maximum string of either ones or zeros be limited to 64 bits;

(2) that, for Category A, a minimum of 125 transitions occur in any sequence of 1000 consecutive symbols;[1]

(3) that, for Category B, a minimum of 275 transitions occur in any sequence of 1000 consecutive symbols;[1]

NOTE:

1. See: *CCSDS Recommendation for Packet Telemetry*, CCSDS 102-B-2, January 1987, or later issue and *CCSDS Recommendation for Telemetry Channel Coding*, CCSDS 101.0-B-2, January 1987, or later issue to determine the recommended method(s) for ensuring adequate symbol transition density.

2.4.10 CHANNEL INPUT AND CODING CONVENTIONS FOR QPSK SYSTEMS

The CCSDS,

considering

(a) that a clear relation between digital information and the resulting RF carrier phase is necessary to reconstruct the digital data stream following reception and demodulation;

(b) that the digital data format will conform to the CCSDS Recommendation for *Packet Telemetry*;

(c) that some communications systems with high data rate transmission requirements use QPSK modulation;

(d) that the phase states representing each of the possible debit values should be judiciously chosen so that a phase error of 90 degrees can cause an error in no more than one bit;

(e) that it should be possible to have two logically independent channels;

(f) that in the case of a single data stream the odd and even bits should be forwarded to two independent channels;

recommends

(1) that the serial input digital data stream to QPSK systems be divided so that odd bits are modulated on the I-channel and even bits are modulated on the Q-channel.

(2) that carrier phase states have the following meanings:

- 0 degrees represents a “00” bit pair,
- 90 degrees represents a “01” bit pair,
- 180 degrees represents a “11” bit pair,
- 270 degrees represents a “10” bit pair.

2.5.1A MINIMUM EARTH STATION GROUP DELAY CALIBRATION ACCURACY, CATEGORY A

The CCSDS,

considering

(a) that earth station group delay calibrations must include all equipment used for ranging measurements;

(b) that the path used for earth station group delay calibration is not always identical with the path used for ranging measurements;

(c) that earth station group delay calibrations require frequency translation to close the loop between the earth station's transmitting and receiving equipment;

(d) that frequency translation requires the use of a transponder or frequency translator which will not be in the path during ranging measurements;

(e) that the group delay measurement error, exclusive of frequency translation, can reasonably be kept as low as 2 nanoseconds;

(f) that the group delay measurement error of the frequency translation equipment can also be kept as low as 2 nanoseconds;

(g) that, where a frequency translator is employed to close the loop between the earth station's transmitting and receiving equipment, the ranging tone modulation indices used for up- and/or down-link during calibrations are generally not the same as those used during ranging measurements;

(h) that the group delay variation of the earth station receiver resulting from the use of different modulation indices does not exceed 4 nanoseconds;

(i) that the calibration error due to spurious modulation in the earth station's equipment does not exceed 2 nanoseconds;

recommends

that the earth station's group delay be calibrated with an accuracy better than, or equal to, 10 nanoseconds for Category A missions.

2.5.2A MINIMUM EARTH STATION RANGING GROUP DELAY STABILITY, CATEGORYA

The CCSDS,

considering

(a) that most space agencies use ranging measurements for spacecraft orbit or trajectory determination;

(b) that a ranging accuracy of 10 meters is generally adequate to meet the orbit or trajectory determination accuracy required by Category A missions;

(c) that the accuracy of the ranging measurement is dependent upon the following factors:
- the accuracy with which the station has been located on a geodetic grid;
- the accuracy with which the medium can be modeled;
- the accuracy of the frequency and timing system;
- the accuracy with which the ranging channel’s group delay has been calibrated;
- the ranging data noise;
- the group delay variations between calibrations;

(d) that the ground system’s contribution to the total 10 meter ranging error can be limited to 30 percent of the total;

(e) that the elapsed time between the ranging calibration and the actual measurement can be limited to 12 hours or less;

recommends

that the total group delay variation in the ground station ranging equipment, over any 12 hour period, shall not exceed 20 nanoseconds.

2.5.2B MINIMUM EARTH STATION RANGING GROUP DELAY STABILITY, CATEGORYB

The CCSDS,

considering

(a) that most space agencies use ranging measurements for spacecraft orbit or trajectory determination;

(b) that precision range measurements are frequently required to meet the scientific objectives of Category B missions;

(c) that the ranging data can yield scientific information about the medium and other physical phenomena;

(d) that the value of the information obtained from the ranging measurement for scientific purposes is directly related to its accuracy;

(e) that to satisfy the needs of all users, the ranging system should be capable of measurement accuracies of three meters or better;

(f) that the accuracy of the ranging measurement is dependent upon the following factors:
- the accuracy with which the station has been located on a geodetic grid;
- the accuracy with which the medium can be modeled;
- the accuracy of the frequency and timing system;
- the accuracy with which the ranging channel's group delay has been calibrated;
- the ranging data noise;
- the group delay variations between calibrations;

(g) that, in order to meet the measurement accuracies set forth in (e) above, it is important to control the magnitude of the error sources listed in (f) above;

(h) that group delay variations in the ground station ranging equipment, which occur between calibrations of that delay, should not exceed ten percent of the total error budget;

(i) that the elapsed time between the ranging calibration and the actual measurement can be limited to 12 hours or less;

(j) that short term variations in group delay affect range rate measurements which are sometimes required for range measurement;

recommends

(1) that the total group delay variation in the ground station ranging equipment, over any 12 hour period, shall not exceed 2 nanoseconds.

(2) that the derivative of the group delay (in a mean square sense) with time is within ± 0.1 mm/s.

2.5.3A MINIMUM SPACECRAFT RANGING CHANNEL GROUP DELAY STABILITY, CATEGORY A

The CCSDS,

considering

(a) that most space agencies use ranging measurements for spacecraft orbit or trajectory determination;

(b) that a distance measurement accuracy of 10 meters is generally adequate to meet the orbit or trajectory determination accuracies required by Category A missions;

(c) that the highest frequency ranging signal determines the precision of the range measurement;

(d) that the principal delay encountered by the highest frequency ranging signal results from the narrow band filter in the transponder's ranging channel;

(e) that, in the absence of thermal noise, the spacecraft transponder's contribution to the total 10 meter ranging error should not exceed 15 percent of the total;

(f) that transponder ranging channel phase linearity is desirable since it facilitates removing the range ambiguities;

(g) that a linear phase response of transponder's ranging channel can be achieved with a four-pole Bessel bandpass filter having a one-sided bandwidth of 200 kHz and a group delay of 10 microseconds;

(h) that a group delay stability of a few percent is easily achievable for such a filter;

recommends

(1) that the delay variation of the highest frequency ranging signal, which occurs in the spacecraft's transponder, shall not exceed ± 50 nanoseconds;

(2) that pre-launch calibrations, together with telemetered data (voltage, temperature, static phase error, etc.) be sufficient to permit calculation of the transponder's ranging channel group delay with an accuracy of ± 5 nanoseconds at any time;

(3) that recommendations (1) and (2) are applicable over the full range of doppler frequencies, input signal level, temperatures, and voltages encountered during the mission's lifetime;

NOTE:

1. For ranging transponder bandwidth, refer to Recommendation 401 (2.5.4A).

2.5.3B MINIMUM SPACECRAFT RANGING CHANNEL GROUP DELAY STABILITY, CATEGORY B

The CCSDS,

considering

(a) that most space agencies use ranging measurements for spacecraft orbit or trajectory determination;

(b) that a distance measurement accuracy of 3 meters is generally adequate to meet the orbit or trajectory determination accuracies required by Category B missions;

(c) that the highest frequency ranging signal determines the precision of the range measurement;

(d) that the principal delay encountered by the highest frequency ranging signal results from the narrow band filter in the transponder's ranging channel;

(e) that, in the absence of thermal noise, the spacecraft transponder's contribution to the total 3 meter ranging error should not exceed 25 percent of the total;

(f) that transponder ranging channel phase linearity is desirable since it facilitates removing the range ambiguities;

(g) that a linear phase response of transponder's ranging channel can be achieved with a four-pole Bessel bandpass filter having a one-sided bandwidth of 3.5 MHz and a group delay of 600 nanoseconds;

(h) that a filter group delay stability of a few percent is easily achievable;

(i) that transponders with two or more space-to-earth links having frequency diversity provide a means for determining range measurement errors induced by charged particles if the group delay difference(s) between the transponder's ranging channels is known with great accuracy;

recommends

(1) that the delay variation of the highest frequency ranging signal, which occurs in the spacecraft's transponder, shall not exceed ± 30 nanoseconds;

(2) that pre-launch calibrations, together with telemetered data (voltage, temperature, static phase error, etc.) be sufficient to permit calculation of the transponder's ranging channel group delay with an accuracy of ± 2.5 nanoseconds at any time;

(3) that the variation in differential delay between any two channels in a single transponder be less than ± 2 nanoseconds;

(4) that the above recommendations are applicable over the full range of doppler frequencies, input signal level, temperatures, and voltages encountered during the mission's lifetime;

NOTE:

1. For ranging transponder bandwidth, refer to Recommendation 401 (2.5.4B).

2.5.4A RANGING TRANSPONDER BANDWIDTH FOR RESIDUAL CARRIER SYSTEMS, CATEGORY A

The CCSDS,

considering

(a) that, for most missions, the ranging signals occupy a larger bandwidth than telecommand or housekeeping telemetry signals;

(b) that it is important to limit the occupied bandwidth in the Category A mission frequency bands;

(c) that sine-wave ranging modulation is used for limiting the occupied bandwidth;

(d) that range measurement precision increases with the frequency of the highest frequency (major) ranging tone;

(e) that most space agencies presently utilize a 100 kHz major tone as a compromise between range measurement precision and bandwidth occupancy;

(f) that most space agencies currently employ tones at or above 4 kHz;

(g) that the spacecraft transponder’s ranging filter must reject d.c. and very low frequencies so that the residual carrier energy is not re-modulated on the return link;

(h) that it is important to minimize earth-to-space link noise which is re-modulated on the space-to-earth link;

(i) that high phase linearity of the spacecraft transponder’s ranging channel filter over its bandwidth facilitates removing range ambiguities when multiple range tones are used;

(j) that the ranging transponder’s bandwidth can be adequately controlled using a 4-pole Bessel linear-phase bandpass filter which properly defines the attenuation roll-off characteristics;

recommends

(1) that spacecraft transponders incorporate a bandpass filter in their ranging channel;

(2) that the transponder ranging channel’s baseband frequency response be uniform within ± 0.5 dB within the frequency range 3 kHz to 110 kHz;

(3) that the transponder’s ranging channel be designed to not deviate more than ± 6 degrees from a linear phase-frequency relationship within the bandwidth stated in *recommends (2)*.

2.5.4B RANGING TRANSPONDER BANDWIDTH FOR RESIDUAL CARRIER SYSTEMS, CATEGORY B

The CCSDS,

considering

(a) that range measurement precision increases with the frequency of the highest frequency (major) range code component;

(b) that some space tracking systems for Category B missions employ square-wave ranging modulation having range code component frequencies from 1 Hz to 1 MHz;

(c) that other spacecraft tracking systems for Category B missions employ sine wave tones, which can be selected in frequency from 100 kHz to 1 MHz, which may be phase modulated by a square wave code;

(d) that these systems are designed to bi-phase modulate the high frequency code component with the low frequency code components to reduce interference with the telecommand and telemetry signals;

(e) that the ranging transponder's bandwidth required to accommodate the ranging codes described in (b) permit flexibility in the selection of the types of ranging codes and modulation techniques;

(f) that the ranging transponder's bandwidth can be adequately controlled using a 4-pole Bessel linear-phase bandpass filter which properly defines the attenuation roll-off characteristics;

(g) that some margin should be included in the transponder filter's bandwidth to ensure proper operation with the commonly used 1 MHz tone or code;

recommends

(1) that spacecraft transponders incorporate a bandpass filter in their ranging channel;

(2) that the transponder ranging channel's baseband frequency response be uniform within ± 0.5 dB within the frequency range 3 kHz to 1.1 MHz;

(3) that the one-half power (-3 dB) bandpass frequencies of the transponder's ranging channel be greater than 3 MHz and less than 1 kHz;

(4) that the transponder's ranging channel be designed to not deviate more than ± 6 degrees from a linear phase-frequency relationship within the bandwidth stated in *recommends (3)*;

(5) that the one-sided equivalent noise bandwidth be limited to 3.5 MHz.

2.5.5A PN CODE PHASE SHIFT STABILITY REQUIRED IN SPACECRAFT SPREAD SPECTRUM REGENERATIVE RANGING TRANSPONDERS,CATEGORY A

The CCSDS,

considering

(a) that most agencies use ranging measurements for spacecraft orbit or trajectory determination;

(b) that Pseudo-Noise (PN) code sequences are used by some spacecraft transponders to make ranging measurements;

(c) that, in the ranging mode, these transponders must synchronize an on-board PN code generator to the received PN code;

(d) that, usually, the earth-to-space link's signal-to-noise ratio in the ranging code's tracking loop is sufficiently large so that the phase error in the spacecraft's code tracking loop is an insignificant part of the ranging measurement error;

(e) that a 1-sigma distance measurement accuracy of 10 meters is generally sufficient to meet the orbit or trajectory determination requirements of Category A missions;

(f) that the spacecraft transponder's contribution to the total 10 meter distance measurement error should not exceed 30 percent of the total;

(g) that the variation of transponder's temperature is the principal cause of instability in the time delay and is normally measured and recorded prior to launch;

recommends

that the time delay of PN codes through a spacecraft's transponder should not vary from its calibrated, pre-launch value by more than 20 nanoseconds.

2.6.1 TRANSPONDER TURNAROUND FREQUENCY RATIOS FOR THE 2025—2120 MHz AND 2200—2300 MHz BANDS

The CCSDS,

considering

(a) that a great number of space missions, which require coherency between the earth-to-space and space-to-earth links for development of navigational data, operate in the above frequency bands;

(b) that for space missions which require coherency, a turnaround frequency ratio must be defined;

(c) that many CCSDS agencies have used the 221/240 turnaround ratio in their space missions for many years;

(d) that many CCSDS agencies have developed equipment using this ratio for their spacecraft and earth stations which represent a large financial investment;

(e) that the 221/240 turnaround frequency ratio adequately translates the 2025 - 2120 MHz band to the 2200 - 2300 MHz band;

recommends

(1) that CCSDS agencies continue to use the 221/240 turnaround frequency ratio for Category A and Category B space missions which are operating in the above bands;

(2) that this turnaround frequency ratio is only necessary for those space missions which require both cross support from other agencies' earth stations and coherency between the earth-to-space and space-to-earth links.

2.6.2 TRANSPONDER TURNAROUND FREQUENCY RATIOS FOR THE 7145—7235 MHz AND 8400—8500 MHz BANDS

The CCSDS,

considering

(a) that a great number of space missions which require coherency between the earth-to-space and space-to-earth links for development of navigational data operate in the above frequency bands;

(b) that for space missions which require coherency, a turnaround frequency ratio must be defined;

(c) that some CCSDS agencies have used the 749/880 turnaround ratio for several years and others are planning its use for the near future;

(d) that some CCSDS agencies have developed equipment using this ratio for their spacecraft and earth stations and others are planning to do so in the near future, representing a large financial investment;

(e) that the 749/880 turnaround frequency ratio adequately translates the 7145 - 7235 MHz band to the 8400 - 8500 MHz band;

recommends

(1) that CCSDS agencies use the 749/880 turnaround frequency ratio for their Category A and Category B space missions operating in the 7145 - 7235 and 8400 - 8500 MHz bands;

(2) that this turnaround frequency ratio is only necessary for those space missions which require both cross support from other agencies’ earth stations and coherency between the earth-to-space and space-to-earth links.

2.6.3A TRANSPONDER TURNAROUND FREQUENCY RATIOS FOR THE 2025—2110 MHz AND 8450—8500 MHz BANDS, CATEGORY A

The CCSDS,

considering

(a) that future Category A space missions will use earth-to-space links in the 2025 - 2110 MHz band in conjunction with space-to-earth links in the 8450 - 8500 MHz band;

(b) that these space missions may require coherency between the earth-to-space and space-to-earth links for the development of navigational data;

(c) that for space missions which require coherency, a turnaround frequency ratio must be defined;

(d) that the two frequency bands under consideration differ regarding the available bandwidth;

(e) that the lower and upper parts of the 2025-2110 MHz band are already rather densely occupied by long term missions and, consequently, they should be avoided;

(f) that for reasons of standardization of the on-board receiver design, a ratio between the two bands under consideration should be chosen in such a way as to conserve the number “221” of the “221/240” ratio for 2 GHz downlink/uplink systems;

(g) that for reasons of simplicity of on-board transmitter design, a ratio which can be divided down to small integers should be selected;

recommends

(1) that CCSDS agencies use a turnaround frequency ratio of 221/900 for systems operating in the 2075 - 2087 MHz and 8450 - 8500 MHz bands;

(2) that this turnaround frequency ratio is only necessary for those space missions which require both cross support from other agencies’ earth stations and coherency between the earth-to-space and space-to-earth links.

2.6.4A TRANSPONDER TURNAROUND FREQUENCY RATIOS FOR THE 7190—7235 MHz AND 2200—2290 MHz BANDS, CATEGORY A

The CCSDS,

considering

(a) that future Category A space missions will use earth-to-space links in the 7190 - 7235 MHz band in conjunction with space-to-earth links in the 2200 - 2290 MHz band;

(b) that these space missions may require coherency between earth-to-space and space-to-earth links for the development of navigational data;

(c) that for space missions which require coherency, a turnaround frequency ratio must be defined;

(d) that the two frequency bands under consideration differ regarding the available bandwidth;

(e) that the lower and upper parts of the 2200 - 2290 MHz band are already rather densely occupied by long term missions and, consequently, they should be avoided;

(f) that in many cases, the 2 GHz transponder will not be modified, and the 7 GHz earth-to-space link can be considered as optional;

(g) that a design goal of the 2/8 GHz transponder should be a simplicity of interfaces and system flexibility;

(h) that similarity of the circuit layout with the transponders developed for the deep space frequency bands may make hardware reuse possible;

recommends

(1) that CCSDS agencies use a turnaround frequency ratio of 765/240 for systems operating in the 7190 - 7235 MHz and 2256 - 2270 MHz bands;

(2) that this turnaround frequency ratio is only necessary for those space missions which require both cross support from other agencies' earth stations and coherency between the earth-to-space and space-to-earth links.

2.6.5B TRANSPONDER TURNAROUND FREQUENCY RATIOS FOR THE 2110—2120 MHz AND 8400—8450 MHz BANDS, CATEGORY B

The CCSDS,

considering

(a) that Category B space missions use earth-to-space links in the 2110 - 2120 MHz band in conjunction with space-to-earth links in the 8400 - 8500 MHz band;

(b) that many of these space missions require coherency between the earth-to-space and space-to-earth links for the development of navigational data;

(c) that for space missions which require coherency, a turnaround frequency ratio must be defined;

(d) that for reasons of standardization of the on-board receiver design, a ratio between the two bands under consideration should be chosen in such a way as to conserve the number “221” of the “221/240” ratio for 2 GHz uplink/downlink systems;

(e) that for reasons of simplicity of on-board transmitter design, a ratio which can be divided down to small integers should be selected;

(f) that some CCSDS agencies utilize a turnaround frequency ratio of 221/880 and others are planning to do so in the near future;

recommends

(1) that CCSDS agencies use a turnaround frequency ratio of 221/880 for their Category B missions operating in the 2110 - 2120 MHz and 8400 - 8450 MHz bands;

(2) that this turnaround frequency ratio is only necessary for those space missions which require both cross support from other agencies’ earth stations and coherency between the earth-to-space and space-to-earth links.

2.6.6B TRANSPONDER TURNAROUND FREQUENCY RATIOS FOR THE 7145 — 7190 MHz AND 2290 — 2300 MHz BANDS, CATEGORY B

The CCSDS,

considering

(a) that Category B space missions will use earth-to-space links in the 7145 - 7190 MHz band in conjunction with space-to-earth links in the 2290 - 2300 MHz band;

(b) that many of these space missions require coherency between the earth-to-space and space-to-earth links for the generation of navigational data;

(c) that for space missions which require coherency, a turnaround frequency ratio must be defined;

(d) that for reasons of standardization of on-board receiver design, a turnaround frequency ratio containing the number “749” of the “749/880” ratio for the 7 GHz uplink/8 GHz downlink systems should be selected;

(e) that for reasons of standardization of on-board transmitter design, a turnaround frequency ratio containing the number “240” of the “221/240” ratio for 2 GHz uplink/downlink systems should be selected;

recommends

(1) that CCSDS agencies use a turnaround frequency ratio of 749/240 for Category B missions operating in the 7145 - 7190 MHz and 2290 - 2300 MHz bands;

(2) that this turnaround frequency ratio is only necessary for those space missions which require both cross support from other agencies’ earth stations and coherency between the earth-to-space and space-to-earth links.

RECOMMENDATIONS 2.6.7 THROUGH 2.6.11

RESERVED FOR 13 — 15 GHz AND 32 — 34 GHz TRANSPONDER TURNAROUND FREQUENCY RATIO

2.6.12 SPACECRAFT TRANSPONDER IF AND AGC AMPLIFIER BANDWIDTHS FOR COHERENT OPERATION

The CCSDS,

considering

(a) that most space agencies utilize spacecraft receivers employing phase-locked loops;

(b) that most of these receivers are implemented as double conversion superheterodyne radios with two stage i.f. bandpass filters, and automatic gain controls (AGC);

(c) that a spacecraft's transponder is said to be operating coherently if its receiver is phase-locked to a signal, f_r , an earth station and the spacecraft's transmitted signal, f_t , is a rational multiple of f_r, such that: $f_t = (m/n)f_r$, where m and n are integer numbers and the ratio (m/n) is called the transponder turnaround frequency ratio;

(d) that the predetection i.f. bandpass filters' bandwidths and the carrier AGC loop's bandwidth are very important in determining the spacecraft receiver's phase-locked loop operation;

(e) that the predetection bandwidths must be neither too large nor too small because the former can result in a degraded signal-to-noise ratio while the latter produces false locks during acquisition of the earth-to-space link;

(f) that for Category A missions, where the earth-to-space signal strength can vary both rapidly and substantially, it is the practice to design AGC loops with a fast response;

(g) that for Category B missions, where the earth-to-space signal strength generally changes slowly and slightly, it is the practice to design AGC loops with a slow response;

(h) that, when the spacecraft's receiver is operating in an unlocked mode, the AGC amplifier's gain is determined by the total received signal plus noise power while, when it is operating in a phase-locked mode, the AGC amplifier's gain is determined solely by the received carrier's signal power;

recommends

(1) that the spacecraft transponder's turnaround frequency ratios be selected from those contained in Section 2.6 of this book;

(2) that the spacecraft's transponder have two-sided predetection filter bandwidths of not less than 250 kHz followed by a second filter of not less than 3 kHz;

(3) that, for Category A missions, spacecraft transponders be designed to permit selection of the two-sided carrier AGC loop bandwidth over a range of at least 15 Hz to 45 Hz depending upon mission conditions;

(4) that, for Category B missions, spacecraft transponders be designed to permit selection of the two-sided carrier AGC loop bandwidth over a range of at least 1 Hz to 3 Hz depending upon mission conditions;

(5) that the spacecraft transponder's AGC include coherent and non-coherent detectors.

3.0 POLICY RECOMMENDATIONS

Section 2 concerns itself with Recommendations pertaining to Radio Frequency and Modulation systems' technical characteristics. By contrast, this chapter focuses upon radio frequency spectrum usage.

Rules governing a user's operations in the frequency bands are as important as the equipment's technical specifications. As crowding of the RF spectrum increases, standards become an imperative to order. In a broad sense, the International Telecommunication Union (ITU) establishes high-level spectrum policy with its Radio Regulations. Here, the principal concern is with establishing lower-level Recommendations promoting the most efficient use of the ITU's frequency allocations.

These policies are intended to supplement, not supplant, those promulgated by the ITU. This goal is reached by increasing the relevance of specific ITU regulations to spacecraft communications. Each Recommendation begins with applicable provisions of the ITU's Radio Regulations as a foundation and provides additional guidelines for that particular application.

By establishing the following agreements, the CCSDS agencies hope to significantly reduce spectrum congestion. Then, the potential for mutual interference in spacecraft communications should decrease accordingly.

A significant number of new Recommendations are concerned with Policy. Filing all such Recommendations in a single section makes them difficult to locate and promotes disorder. Accordingly, there are now six *Policy* sub-sections:

3.1	*Frequency Utilization*	3.4	*Operational Procedures*
3.2	*Power Limitations*	3.5	*Testing Recommendations*
3.3	*Modulation Methods*	3.6	*Spacecraft Systems*

These sub-sections are intended to be general categories into which *Policy* Recommendations can be filed and which will simplify a readers task in locating specific items.

FREQUENCY UTILIZATION RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
3.1.1	2 GHz System Parameters	Efficient use of 2 GHz band by satellite missions.
3.1.2.A	10 MHz Occupied BW	Max Cat A telemetry bandwidth in 8 GHz band.
3.1.3A	> 10 MHz Occupied BW	Cat A missions should use 13-15 GHz band.
3.1.4A	Constraints	Cat A constraints on use of 13-15 GHz band.
3.1.5B	31.8-32.3 ; 34.2-34.7 GHz	Reserved for Cat B missions.
3.1.6B	Channel Frequencies	Cat B channel frequency plan for 2, 7, and 8 GHz.

POWER LIMITATIONS RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
3.2.1	EIRP Levels	Limitations on earth-to-space link.

MODULATION METHODS RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
3.3.1	Sine Wave ; Square Wave	Cat A; Cat B ranging modulation waveforms.
3.3.2A	Spread Spectrum	Cat A criteria for use of spread spectrum modulation.
3.3.3A	OQPSK ; QPSK	Cat A criteria for use.

OPERATIONAL PROCEDURES RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
3.4.1	Simultaneous Rng, Cmd, Tlm	Design spacecraft for simultaneous operations.
3.4.2	Measurement Methods	Charged particle measurement methods.

TESTING RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
3.5.1	Test Names	Min spacecraft-earth station compatibility tests.

SPACECRAFT SYSTEMS RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
3.6.1A	Power Spectral Density	Constraints on space-to-space links.

3.1.1 EFFICIENT UTILIZATION OF THE 2 GHz BANDS BY SATELLITE MISSIONS

The CCSDS,

considering

(a) that frequency bands 2025 - 2110 and 2200 - 2290 MHz are shared co-equally by the following space services: Space Research, Space Operation, and Earth Exploration Satellite (EES);

(b) that these bands constitute mission bands for the Space Research and EES services and tracking, telemetry, and telecommand (TTC) bands for other space services making use of the Space Operation service allocations;

(c) that these bands are of prime importance for the satellite missions of CCSDS agencies and will remain so for many years to come as no comparable alternative frequency allocations are available;

recommends

that, in order to make maximum use of these bands for satellite missions of all kinds, appropriate technical and operational constraints be observed, particularly:

i The TTC systems for geostationary satellites should be designed and constructed to the general characteristics contained in CCIR Report 678, Dubrovnik, 1986, as set forth in Table 3.1.1-1. Given the state-of-the-art in satellite receiver technology as demonstrated by numerous existing 2 GHz TTC systems, higher earth station EIRPs are not desired and will be detrimental to the effective use of the RF spectrum as well as the geostationary orbit.

ii Space systems, which are designed to operate in mission bands other than 2025 - 2110 MHz and 2200 - 2290 MHz, but which utilize TTC systems within these bands, should limit the use of such TTC systems to launch, orbit insertion, and emergency operations in accordance with the definition of the Space Operation service (ITU/RR/25). By limiting the use of such TTC systems, the possibility of interference between spacecraft operating in the Space Operation, Space Research, and Earth Exploration Satellite (EES) services will be greatly reduced.

iii With a view to facilitating sharing of the 2 GHz bands, TTC and data transmission systems on spacecraft operating in the Space Research and Earth Exploration Satellite services should also be designed in such a way that the occupied bandwidths in the earth-to-space and space-to-earth links, as well as earth stations’ EIRPs, are kept to a minimum.

3.1.1 EFFICIENT UTILIZATION OF THE 2 GHz BANDS BY SATELLITE MISSIONS (Continued)

TABLE 3.1.1-1

TYPICAL SYSTEM PARAMETERS AT 2 GHz

MODE	SYSTEM PARAMETERS	SPACE OPERATIONS (up to geostationary altitude)
Reception at earth station	Telemetry bandwidth Tracking bandwidth G/T, earth stations	100 kHz 400 kHz Approx. 20 dB/K
Transmission from earth stations	Telecommand bandwidth Tracking bandwidth EIRP, earth station	100 kHz 400 kHz Approx. 65 dBW

3.1.2A USE OF THE 8450—8500 MHz BAND FOR SPACE RESEARCH, CATEGORY A

The CCSDS,

considering

(a) that the 8450 - 8500 MHz band contains the only primary worldwide allocation to the Space Research service below 40 GHz, affording it particularly good protection from interference;

(b) that the total allocated bandwidth is limited to 50 MHz;

(c) that CCIR Recommendation 610 sets the limit for Category A missions at 2,000,000 km instead of lunar distance as currently defined in the ITU Radio Regulations (cf. ITU/RR/169);

(d) that space missions to the region between lunar distance and 2,000,000 km will need spectrum accommodation outside the deep space bands, in accordance with (c);

(e) that space missions mentioned under (d) may have technical requirements, which can only be satisfied in the 8450 - 8500 MHz bands;

(f) that certain space missions have a 2/8 GHz coherency requirement, determined by mission objectives;

recommends

(1) that space missions requiring an occupied bandwidth, as defined in ITU/RR/147, of more than 20% of the available bandwidth (i.e., in excess of 10 MHz) should not be approved for a frequency assignment in the 8450 - 8500 MHz band without detailed consideration of their requirements;

(2) that space missions mentioned in (d), (e), and (f) above should be given priority for use of the 8450 - 8500 MHz band;

(3) that CCSDS agencies approve space missions with bandwidth requirements in excess of 10 MHz in the 8450 - 8500 MHz band only on a case-by-case basis and impose, where necessary, operational limitations on their use of this band.

3.1.3A USE OF THE 13.25—15.35 GHz BANDS FOR SPACE RESEARCH, CATEGORY A

The CCSDS,

considering

(a) that frequency bands are allocated to the Space Research service between 13.25 and 15.35 GHz, i.e.,

13.25 - 13.40 GHz (earth-to-space)
13.40 - 14.30 GHz (no direction indicated)
14.40 - 14.47 GHz (space-to-earth)
14.50 - 15.35 GHz (no direction indicated)

(b) that these bands are allocated with a secondary status and consequently may not enjoy full protection from interference at all sites and all times;

(c) that these bands were found feasible for use with near-earth satellites in CCIR Recommendation 364;

(d) that a link near 15 GHz may provide about 1.5-2.5 dB improvement in the space-to-earth link compared to the current 8 GHz band, while a link near 33 GHz may provide 5.0-7.7 dB improvement compared to 8 GHz;

(e) that the limits of power flux density on the earth's surface for the 13.4 - 15.35 GHz bands are specified by CCIR Recommendation 510-1 to be:

-148 dB (W/m^2) in any 4 kHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;

-148 + 0.5 (delta - 5) dB (W/m^2) in any 4 kHz band for angles of arrival, delta (degrees) between 5 and 25 degrees above the horizontal plane;

-138 dB (W/m^2) in any 4 kHz band for angles of arrival between 25 and 90 degrees above the horizontal plane;

(f) that these PFD limits allow operation of earth stations with G/Ts of typically 35-40 dB/K;

3.1.3A USE OF THE 13.25—15.35 GHz BANDS FOR SPACE RESEARCH, CATEGORY A (continued)

recommends

that the 13.25 - 15.35 GHz frequency bands of the Space Research service be used for Category A satellites, particularly with those missions having requirements for large bandwidths, which cannot be accommodated in other frequency bands of this service (such as in the 2 and 8 GHz bands).

NOTE:

1. **The Tracking and Data Relay Satellite System (TDRSS) uses the 13.25 to 15.35 GHz band with the 13.4 to 14.0 GHz portion being used for space-to-earth and TDRSS-to-user (satellite) transmissions. This lower portion of the band is susceptible to interference from Category A missions and consequently should be used with due consideration to the TDRSS use. (Sharing of this portion of the band may be feasible in certain circumstances, e.g., if transmissions of the near-earth spacecraft are pointed at the earth only and are restricted to those parts of the orbit where no interference will be carried to the White Sands, NM TDRSS earth station.)**

3.1.4A CONSTRAINTS ON THE USE OF THE 13.25—15.35 GHz BAND FOR SPACE RESEARCH, CATEGORY A

The CCSDS,

considering

(a) that bandwidth requirements in excess of 10 MHz are increasingly difficult to satisfy in frequency bands allocated to the Space Research Service below 10 GHz;

(b) that the 8450 - 8500 MHz band has been identified as appropriate for Category A missions requiring less than 10 MHz of bandwidth as specified in Recommendation 401 (3.1.2A) B-1;

(c) that the sharing situation in this band, where the Space Research Service has only a secondary status, is difficult and does not lend itself to the use of classical modulation schemes which exhibit a high interference potential and a high susceptibility to interference;

(d) that spectrum spreading types of modulation can considerably alleviate the sharing problems addressed in (c) above;

(e) that some CCSDS member agencies are actively pursuing plans for space research missions which require very large bandwidths, e.g., spaceborne VLBI, geodesy and geodynamics;

(f) that errors in measurement precision caused by ionospheric effects at about 14 GHz are reduced by a factor of 2.8 as compared to those at 8.4 GHz, for single frequency measurement systems;

(g) that sharing of the 13.25 - 13.40 GHz part of the band (allocated to Space Research, earth-to-space, Secondary, under Article 14) with the Radionavigation service (Primary) is currently impossible;

(h) that the 13.40 - 14.00 GHz part of the band is allocated to the Radiolocation service (Primary) and active sensors on spacecraft (Secondary);

(i) that any use of the 13.40 - 14.00 GHz part of the band by the Space Research Service should be compatible with active sensors in this band;

(j) that, in the 13.40 - 14.00 GHz part of the band, sharing with the Radiolocation Service is difficult and does not lend itself to reception at earth stations, i.e., to space-to-earth transmissions;

(k) that the 14.00 - 15.35 GHz part of the band is densely occupied by the Fixed Service (14.30-15.35 GHz) and earth-to-space links of the Fixed Satellite Service (14.00 - 14.80 GHz) and that, consequently, assignment of earth-to-space links of the Space Research Service are difficult;

(l) that certain parts of the 13.25 - 15.35 GHz band have assignments to data relay satellites;

(m) that CCSDS members should ensure compatibility between their operations in the 13.25 -15.35 GHz band;

3.1.4A CONSTRAINTS ON THE USE OF THE 13.25—15.35 GHz BAND FOR SPACE RESEARCH, CATEGORY A (Continued)

recommends

(1) that the 13.25 - 15.35 GHz band be used only for those Category A space research missions having requirements for occupied bandwidths in excess of 10 MHz;

(2) that use of the 13.25 - 13.40 GHz band by Category A missions requiring an occupied bandwidth of less than 10 MHz be approved only in exceptional cases, with prior coordination by the Space Frequency Coordination Group (SFCG), and after appropriate operational constraints are determined;[1]

(3) that the spectrum of data transmissions in the 13.25 - 15.35 GHz band shall be sufficiently spread so as to ensure adequate protection for other services operating in the band;

(4) that the 13.40 - 14.00 GHz portion of the band be used for earth-to-space transmissions. These transmissions shall not exceed the following EIRP density limits ***(see Figure 3.1.4A-1 on following page);***

$P'(\rho)$	=	$-(20 + 8.8\,\rho^2)$ dBW/Hz;	for $0.0° \leq \rho \leq 1.3°$
$P'(\rho)$	=	-34.4 dBW/Hz;	for $1.3° \leq \rho \leq 1.7°$
$P'(\rho)$	=	$-(28.7 + 25 \log_{10}\rho)$ dBW/Hz;	for $1.7° \leq \rho \leq 48°$
$P'(\rho)$	=	-70.7 dBW/Hz;	for $48° \leq \rho \leq 180°$

where: (ρ) is the off-axis angle.

(5) that use of the 13.25 - 13.40 GHz part of the band not be considered for earth-to-space transmissions at this time;

(6) that particular attention be given to compatibility problems if spaceborne receivers for earth-to-space transmissions and for active sensors, both using the 13.40 - 14.00 GHz band, are located on a common spacecraft;

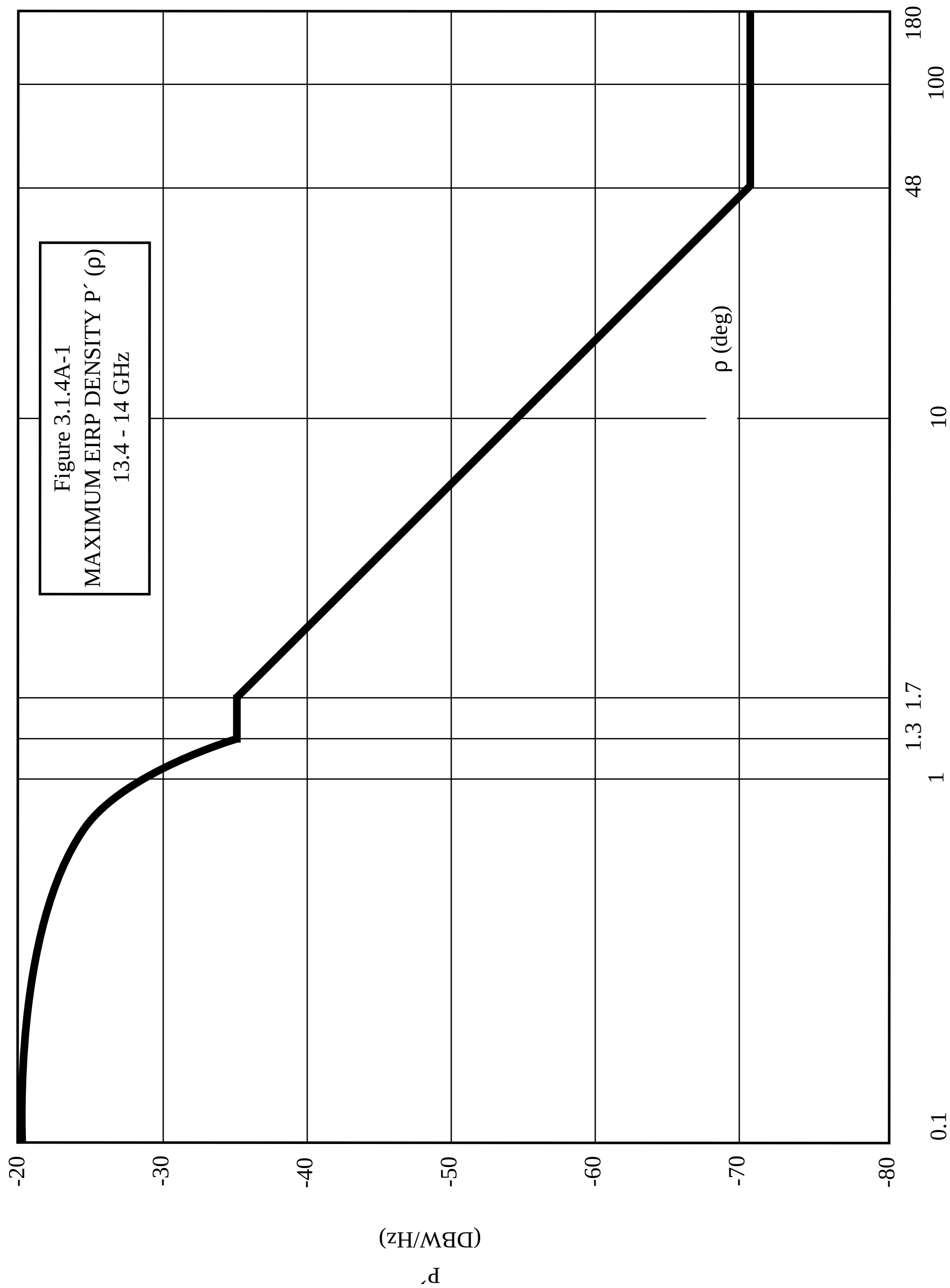
(7) that the 14.00 - 15.35 GHz part of the band be used for space-to-earth transmissions;

(8) that detailed frequency coordination be effected with data relay satellite operators, particularly where frequency assignments near the Tracking and Data Relay Satellite System’s (TDRSS’s) feeder link frequencies are considered.

NOTE:

1. The Frequency Management Office of the CCSDS Agency seeking to use this band is responsible for initiating this action.

3.14A CONSTRAINTS ON THE USE OF THE 13.25—15.35 GHz BAND FOR SPACE RESEARCH CATEGORY (Continued)



3.1.5B USE OF THE 31.8—34.7 GHz BANDS FOR SPACE RESEARCH, CATEGORY B

The CCSDS,

considering

(a) that as spectrum usage increases, the potential for radio frequency interference (RFI) becomes greater;

(b) that telemetry links from missions in deep space, having very weak signals at the earth stations, are particularly susceptible to RFI;

(c) that frequency bands above 15 GHz are currently less crowded than those below 15 GHz;

(d) that allocated bands that are practicable with current or near future technology exist near 33 GHz, in particular:

FREQUENCY ALLOCATIONS IN THE SPACE RESEARCH SERVICE

FREQUENCY BAND (GHz)	DIRECTION	ALLOCATION STATUS
31.8 - 32.3	space-to-earth	Secondary*
34.2 - 34.7	earth-to-space	Secondary*

(e) that a link near 15 GHz may provide about 1.5-2.5 dB improvement in the space-to-earth link compared to the current 8 GHz band, while a link near 33 GHz may provide 5.0-7.7 dB improvement compared to 8 GHz;

(f) that a link near 15 GHz may provide about 5 dB improvement in the earth-to-space link compared to the current 7 GHz band, while a link near 33 GHz may provide an improvement of 10 dB compared to 7 GHz;

(g) that the allocations near 15 GHz and near 33 GHz are secondary; however, the 33 GHz allocation is primary in the U.S., Spain, and Australia, providing it with more protection from interference than is provided to the 15 GHz band;

* Primary for deep space in the U.S., Spain, and Australia. Primary for space research in Bulgaria, Cuba, Hungary, Mongolia, Poland, the German Democratic Republic, Czechoslovakia, and the U.S.S.R.

3.1.5B USE OF THE 31.8—34.7 GHz BANDS FOR SPACE RESEARCH, CATEGORY B (Continued)

(h) that further consideration will have to be given to sharing considerations for either the 15 or 33 GHz bands. However, the 33 GHz band is somewhat better protected;

recommends

(1) that the frequency band:

31.8 - 32.3 GHz	be utilized for Space Research (space-to-earth, Category B only);
34.2 - 34.7 GHz	be utilized for Space Research (earth-to-space, Category B only);

(2) that CCSDS agencies utilize the bands near 33 GHz for communications with Category B missions in preference to those allocated to deep space near 13 and 17 GHz;

(3) that channel plans and transponder turnaround frequency ratios be developed as soon as possible linking the bands near 33 GHz to the 2, 7, and 8 GHz, Category B bands;

(4) that further consideration be given to the allocation status and the study of sharing criteria for the 31.8 - 32.3 and 34.2 - 34.7 GHz bands.

3.1.6B CHANNEL FREQUENCY PLAN FOR 2, 7, AND 8 GHz, CATEGORY B

The CCSDS,

considering

(a) that channel frequency plans for Category B missions exist for the 2, 7, and 8 GHz bands while others are being developed for the 32 and 34 GHz bands;

(b) that the sets of channel frequency pairs in these existing plans are based upon the recommended turnaround ratios;

(c) that members of the Space Frequency Coordination Group (SFCG) have resolved to select frequencies for their Category B missions from the existing channel frequency plans;

(d) that most past, existing, and planned Category B missions have assigned frequencies that were selected on the basis of these existing channel frequency plans;

(e) that CCSDS agencies conducting Category B missions have coordinated the selection of frequencies from those embodied in the existing channel frequency plans in order to avoid interference between missions;

recommends

(1) that CCSDS agencies select frequencies for their Category B missions operating in the 2, 7, and 8 GHz bands from the channel frequency plan contained in Table 3.1.6B-1;

(2) that frequency selection be coordinated with an appropriate organization, such as the SFCG, to ensure the orderly use of the channel frequency plan.

3.1.6B CHANNEL FREQUENCY PLAN FOR 2, 7, AND 8 GHZ, CATEGORY B (Continued)

TABLE 3.1.6B-1: CHANNEL CENTER FREQUENCIES

Channel	2110 - 2120 MHz Uplink Channel Center Frequency (MHz)	2290 - 2300 MHz Downlink Channel Center Frequency (MHz)	7145 - 7190 MHz Uplink Channel Center Frequency (MHz)	8400 - 8450 MHz Downlink Channel Center Frequency (MHz)
1		2290.185185	7147.286265	
2		2290.555556	7148.442131	
3		2290.925926	7149.597994	
4		2291.296296	7150.753857	
5*	2110.243056	2291.666667	7151.909724	8402.777780
6	2110.584105	2292.037037	7153.065587	8404.135803
7	2110.925154	2292.407407	7154.221450	8405.493826
8	2111.266204	2292.777778	7155.377316	8406.851853
9	2111.607253	2293.148148	7156.533179	8408.209876
10	2111.948303	2293.518519	7157.689045	8409.567903
11	2112.289352	2293.888889	7158.844908	8410.925927
12	2112.630401	2294.259259	7160.000771	8412.283950
13	2112.971451	2294.629630	7161.156637	8413.641977
14	2113.312500	2295.000000	7162.312500	8415.000000
15	2113.653549	2295.370370	7163.468363	8416.358023
16	2113.994599	2295.740741	7164.624229	8417.716050
17	2114.335648	2296.111111	7165.780092	8419.074073
18	2114.676697	2296.481481	7166.935955	8420.432097
19	2115.017747	2296.851852	7168.091821	8421.790124
20	2115.358796	2297.222222	7169.247684	8423.148147
21	2115.699846	2297.592593	7170.403550	8424.506174
22	2116.040895	2297.962963	7171.559413	8425.864197
23	2116.381944	2298.333333	7172.715276	8427.222220
24	2116.722994	2298.703704	7173.871143	8428.580248
25	2117.064043	2299.074074	7175.027006	8429.938271
26	2117.405092	2299.444444	7176.182868	8431.296294
27	2117.746142	2299.814815	7177.338735	8432.654321
28	2118.087191		7178.494597	8434.012344
29	2118.428241		7179.650464	8435.370371
30	2118.769290		7180.814838	8436.738395
31	2119.110339		7181.962190	8438.086418
32	2119.451389		7183.118056	8439.444445
33	2119.792438		7184.273919	8440.802468
34**			7185.429783	8442.160493
35			7186.585617	8443.518517
36			7187.741511	8444.876542
37			7188.897375	8446.234566
38				8447.592591
39				8448.950616

*** Channels 5-27 are fully coherent in all four bands.** **** Channels 34-39 frequencies are estimates only.**

3.2.1 LIMITATIONS ON EARTH-TO-SPACE LINK POWER LEVELS

The CCSDS,

considering

(a) that spectral occupation of frequency bands used by space agencies is increasing rapidly;

(b) that in many cases the same frequencies will be shared by several spacecraft;

(c) that excessive EIRP levels radiated from earth stations will make frequency sharing increasingly difficult and result in inefficient use of the radio frequency spectrum;

(d) that Pc/No, Eb/No, and the minimum signal level required due to the limitations of the receiver's dynamic range determine the required EIRP from the earth station;

(e) that the required signal level at the spacecraft's receiver input is frequently the dominant parameter determining the EIRP required from the earth station;

recommends

(1) that CCSDS agencies limit the EIRP levels on the earth-to-space links to those realistically required for safe spacecraft operation which can be achieved in the following ways:

- CCSDS agencies avoid using high power transmitters having a fixed output and adjust their transmitted power level to the minimum needed to meet project requirements;

  - CCSDS agencies obtain the required EIRP by using reasonable antenna diameters in order to reduce both sidelobe radiation and transmitter power levels (Guideline: antenna diameter/RF wavelength equal to or greater than 70);

  - CCSDS agencies place CCIR Recommendation 465-1 as a requirement in antenna specifications;

(2) that spacecraft equipment designers should endeavor to provide equal margins for Pc/No, Eb/No and the minimum signal required to fall within the receiver's dynamic range.

3.3.1 OPTIMAL RANGING MODULATION WAVEFORMS FOR SIMULTANEOUS RANGING, TELECOMMANDING, AND TELEMETRY OPERATIONS

The CCSDS,

considering

(a) that two-way transmissions are employed for making range measurements to a distant spacecraft;

(b) that telecommand and telemetry signals are phase shift-keyed onto the subcarriers and then phase-modulated onto a sinusoidal residual RF carrier [see Recommendations 401 (2.1.1) B-1, 401 (2.4.3) B-1, 401 (2.4.4) B-1];

(c) that telemetry signals may also be directly modulated on the RF carrier in conformance with Recommendation 401 (2.4.7) B-1;

(d) that sine-wave subcarriers are recommended for the telecommand channel [see Recommendation 401 (2.2.2) B-1];

(e) that sine-wave subcarriers are recommended for Category A mission's telemetry channels, and square-wave subcarriers are recommended for Category B mission's telemetry channels [see Recommendation 401 (2.4.5) B-1];

(f) that, for simultaneous telecommand and ranging on the earth-to-space link, the telecommand performance suffers some degradation due to command-ranging cross-modulation components;

(g) that, for simultaneous telemetry and ranging on the space-to-earth link, the telemetry performance may be degraded due to interference from the filtered versions of the uplink ranging, feed-through telecommand, cross-modulation components and noise;

(h) that the timing offset due to different clocks between the telecommand and telemetry may cause serious telemetry bit error rate (BER) degradation;

(i) that the telecommand BER performance is virtually identical for either sine wave or square wave ranging modulation;

(j) that, for Category B missions, the telemetry BER performance is insensitive to the type of ranging waveforms used when operated simultaneously with the ranging on the space-to-earth link;

(k) that the use of a square-wave ranging signal makes the telemetry BER performance more susceptible to data-to-data interference (resulting from the timing offset due to different clocks between the telecommand and telemetry) than the sine-wave ranging;

(l) that, for Category A missions, the telemetry BER performance is sensitive to the timing offset when operated simultaneously with either a square-wave or sine-wave ranging signal;

(m) that for Category B missions, it is important to minimize the required transmitted power level on the space-to-earth link;

3.3.2A CRITERIA FOR USE OF DIRECT SEQUENCE SPREAD SPECTRUM MODULATION, CATEGORY A

The CCSDS,

considering

(a) that frequency bands must often be shared between several users which can result in mutual interference;

(b) that such mutual interference can result in significant link degradation or even unusable links for certain periods of time;

(c) that spread spectrum systems can be designed to tolerate a high level of interference from other communications systems.

(d) that, in some cases, spread spectrum modulation can assist in meeting the PFD limits set forth in the International Telecommunication Union’s *(ITU) Radio Regulations;*

(e) that direct sequence spread spectrum systems can be designed to provide ranging measurements by using the spreading code which eliminates the need for a separate ranging signal;

recommends

(1) that direct sequence spread spectrum modulation be used in any of the following cases:

- where the intra-service sharing conditions are such that other modulation methods will not provide the required performance or mutual compatibility with other transmissions assigned to the same frequency band;
- where the inter-service sharing conditions are such that the susceptibility to actual or potential interference from transmissions in other services assigned to the same frequency band cannot be kept within acceptable limits by other modulation methods;
- where the power flux density limits, as set forth in the *ITU Radio Regulations, Article 28*, cannot be met using other methods;

(2) that spread spectrum systems shall be designed to minimize unwanted emissions in the same allocated frequency band;

(3) that unwanted emissions generated by spread spectrum systems shall conform with applicable protection criteria of radio communications services in other frequency bands.

3.3.3A CRITERIA FOR USE OF QPSK MODULATION IN SUPPRESSED CARRIER SYSTEMS, CATEGORY A

The CCSDS,

considering

(a) that efficient use of RF spectrum resources is becoming increasingly important;

(b) that suppressed carrier systems are more bandwidth and power efficient than are residual carrier systems;

(c) that OQPSK systems are less sensitive to non-linear channel effects than are standard QPSK systems;

(d) that sync word detection hardware for phase ambiguity resolution is simpler in a OQPSK system than is the case with a standard QPSK system;

(e) that standard QPSK and OQPSK systems are widely used modulation techniques in bandwidth limited systems;

recommends

that OQPSK or standard QPSK modulation be used in communications systems operating at frequencies where the available bandwidth is limited (e.g., in the 2 and 8 GHz bands);

3.4.1 SIMULTANEOUS TELECOMMAND, TELEMETRY, AND RANGING OPERATIONS

The CCSDS,

considering

(a) that most space agencies use ranging measurements for spacecraft orbit or trajectory determination;

(b) that precision range measurements are frequently required to meet the scientific objectives of the mission;

(c) that the ranging data can yield scientific information about the medium and other physical phenomena;

(d) that the value of the information obtained from the ranging measurement for scientific purposes is directly related to its accuracy;

(e) that the earth stations tend to be large, complex, and expensive to construct and to operate;

(f) that it is desirable to minimize the amount of earth station time required for the support of missions;

(g) that the quantity of telecommands transmitted to a spacecraft may be sufficiently large that it is desirable to have simultaneous telecommand and ranging operations;

(h) that telemetry transmissions are generally continuous and an interruption for ranging operations may result in the loss of valuable data;

(i) that the amount and accuracy of ranging required for missions makes it desirable to preserve an ability for simultaneous telecommand, telemetry, and ranging operations;

recommends

that all CCSDS agencies design their spacecraft to permit simultaneous telecommand, telemetry, and ranging operations.

3.4.2 CHARGED PARTICLE MEASUREMENTS IN THE TELECOMMUNICATIONS PROPAGATION PATH

The CCSDS,

considering

(a) that the telecommunication system's performance can be affected by the columnar content of charged particles in the propagation path;

(b) that charged particles in the propagation path can result in errors in the range and range rate measurements reducing navigation accuracy;

(c) that navigation accuracy requirements can be very high for some Category B missions;

(d) that the four regions through which a telecommunications signal may pass which contain charged particles are: the Earth's ionosphere, the interplanetary medium, the planetary ionosphere, and the solar corona;

(e) that the Sun-Earth-Probe (SEP) angle is important in selecting a means for measuring charged particles;

(f) that geostationary satellites are not useful for measuring charged particle content for regions beyond the Earth's ionosphere;

(g) that Differenced Range vs. Integrated Doppler (DRVID) only measures variations in the total columnar electron content;

(h) that method(s) utilized for measuring the charged particle content in the propagation path depends upon the region involved;

(i) that Figure 3.4.2-1 shows alternative spacecraft tracking methods which provide information about charged particles in the propagation path;

recommends

(1) that CCSDS agencies utilize the appropriate methods in Table 3.4.2-1 to measure charged particles in the propagation path for the specified operating modes.

(2) that CCSDS agencies utilize the methods and signal sources in Table 3.4.2-2 to measure charged particles in the named regions and to correct the specified data.

3.4.2 CHARGED PARTICLE MEASUREMENTS IN THE TELECOMMUNICATIONS PROPAGATION PATH (Continued)

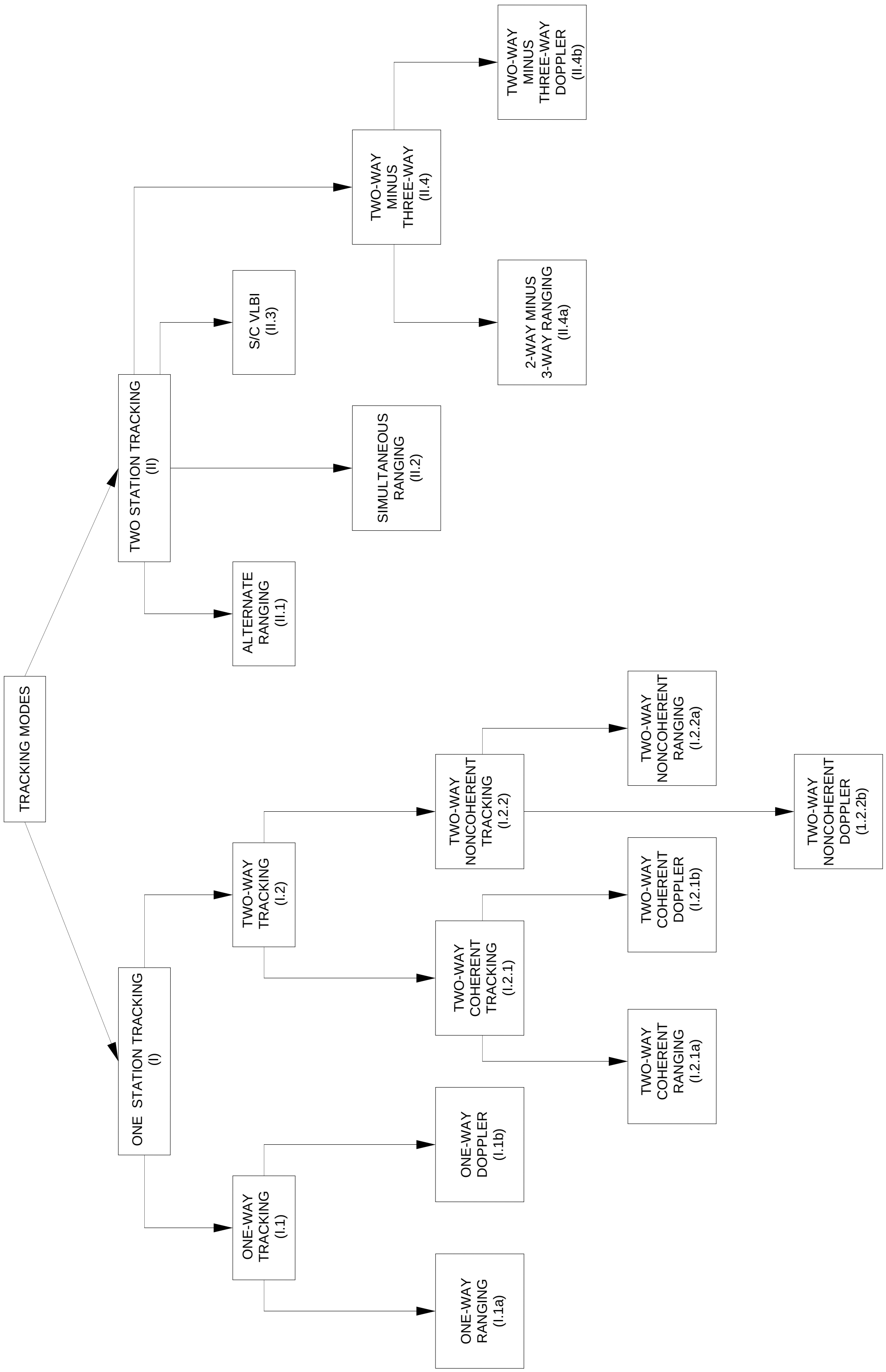


Figure 3.4.2-1: Possible Tracking Modes

3.4.2 CHARGED PARTICLE MEASUREMENTS IN THE TELECOMMUNICATIONS PROPAGATION PATH (Continued)

Table 3.4.2-1: RECOMMENDED CHARGED PARTICLE CALIBRATION METHODS

TRACKING MODE	FARADAY ROT		DRVID	DUAL FREQ		
(see Figure 3.4.2A-1)	user s/c	geo sat	user s/c	user s/c	geo sat	slic [(b)]
I.1a (1-way range)	X	X		X	X	X
I.1b (1-way Doppler)	X	X	X	X	X	X
I.2.1a (2-way coh Rng)	X	X		X	X	X
I.2.1b (2-way coh Dop)	X	X	X	X	X	X
I.2.2a (2-way non-coh Rng)						
I.2.2b (2-way non-coh Dop)			X			
II.1 Alternate Rng	X	X		X	X	X
II.2 Simultaneous Rng	X	X		X	X	X
II.3 S/C VLBI	X	X		(a)		X
II4a (2-way; 3-way Rng)	X	X		X	X	X
II.4b (2-way; 3-way Dop)	X	X	X	X	X	X

NOTES: **(a) is applicable to 2/8 GHz downlink only.**
(b) slic is satellite L-band Ionospheric Calibration.

Table 3.4.2-2: APPLICABILITY OF CALIBRATION METHODS

CALIBRATION METHOD	SOURCE USED	EARTH's IONO-SPHERE	Beyond IONO-SPHERE	RANGE ERROR	RANGE RATE ERROR
FARADAY ROTATION	S/C	X		X(1)	X(1)
	Geo Sat	X		X(2)	X(2)
DUAL FREQUENCY	S/C	X	X	X(3)	X(3)
	Geo Sat	X		X(2)	X(2)
	slic	X		X(2)	X(2)
DIFFERENCED RANGE vs. INTEGRATED DOP	S/C	X	X		
	Geo Sat				

NOTES: **(1) should not be used for SEPs below 5 degrees.**
(2) must translate ray path to user S/C line of sight.
(3) 2/8 GHz downlink only, inaccurate below SEP = 20 deg.

3.5.1 MINIMUM SET OF SPACECRAFT - EARTH STATION TESTS REQUIRED TO ENSURE COMPATIBILITY

The CCSDS,

considering

(a) that cross support will frequently be required for Telemetry, Tracking, and/or Command operation;

(b) that it is desirable to assure compatibility of the spacecraft with the ground network before the launch of a spacecraft;

(c) that this compatibility is usually verified by compatibility tests;

(d) that all parties have a common understanding of the tests;

recommends

that, in accordance with the required cross support, all relevant tests set forth in Table 3.5.1-1 shall be performed.

3.5.1 MINIMUM SET OF SPACECRAFT - EARTH STATION TESTS REQUIRED TO ENSURE COMPATIBILITY (Continued)

Table 3.5.1-1

TEST TYPES
SPACECRAFT RADIO FREQUENCY
Transmitter frequency and frequency stability Transmitter residual carrier phase jitter Transmitter RF spectrum measurement Receiver rest frequency determination Receiver acquisition frequency range and rate Receiver tracking frequency range and rate
TELEMETRY
Telemetry modulation index Telemetry receiver carrier threshold Telemetry bit error rate Telemetry spectrum
TELECOMMAND
S/C receiver command and carrier threshold S/C receiver telecommand phase modulation index variation Telecommand receiver spurious carrier immunity Telecommand receiver spurious modulation immunity
RANGING
Transponder ranging delay Ranging downlink modulation index vs. uplink modulation index Ranging downlink spectrum Ranging downlink modulation index vs. uplink signal-to-noise power
EARTH STATION ANTENNA TRACKING SYSTEM
Receiver carrier signal level threshold

3.6.1A REDUCTION IN INTERFACE FROM SPACE-TO-SPACE LINKS TO OTHER SPACE SERVICES IN THE 2025 - 2110 AND 2200 - 2290 MHz BANDS, CATEGORY A

The CCSDS,

considering

(a) that, in accordance with provisions 747 and 750 of the ITU Radio Regulations, space-to-space links shall not cause harmful interference to other space systems;

(b) that the planned increase in the number of space-to-space links will nevertheless raise the likelihood of harmful interference;

(c) that channel coding techniques, such as concatenated codes, can reduce the power spectral density by more than 10 dB;

(d) that spectrum spreading techniques can also be used to reduce the power spectral density;

recommends

that the power spectral density of space-to-space links be reduced by using appropriate techniques, such as concatenated codes (see CCSDS Recommendation 101.0 B-2) and/or spectrum spreading, in order to reduce the potential for harmful interference to space-to-earth and earth-to-space links.

4.0 PROCEDURAL RECOMMENDATIONS

As telecommunications systems become more sophisticated, it is imperative that aids be developed to assist in the design, performance evaluation, and perhaps even validation of these systems. Early on, the CCSDS was only concerned with technical Recommendations which promoted a uniformity in data systems. However, Subpanel 1E soon discovered that efficient use of the radio frequency spectrum was an imperative. Such efficient use implies constraints and the first Blue Book included a *Policy* section. This section contained many Recommendations limiting CCSDS Agencies use of radio frequencies beyond those already imposed by the ITU's Radio Regulations.

However, efficient use also implies optimal designs. The more efficiently a communications link can be made to operate, the more the frequency spectrum can be shared with other users. Use of the radio frequency bands is increasing so rapidly that sharing has become essential.

This section contains Recommendations intended to assist the CCSDS Agencies to efficiently design and operate their telecommunications links. These Recommendations are, in effect, tools to optimize the design and performance of those links. At this juncture, all Recommendations are in the category of design aids. Accordingly, there is but a single subsection:

4.1 *Design Tools*

However, it is likely that future Recommendations will also cover such areas as performance evaluation and validation.

Many of these tools can be most efficiently applied if they are in the form of computer programs. Work is underway to develop such programs for several Recommendations. These programs are being designed to run on small personal computers of the IBM AT class. Periodically, readers may wish to inquire of either the CCSDS Secretariat, or of CCSDS Subpanel 1E, to ascertain what programs are available.

DESIGN TOOLS RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
4.1.1	Mod Index Determination	Procedure for optimizing.
4.1.2	Link Design Control Table	Standard form for information exchange.
4.1.3	Terminology	Definitions of terms found in DCT.
4.1.4	Reserved	DCT probability density functions.

4.1.1 SELECTION OF OPTIMUM MODULATION INDICES FOR SIMULTANEOUS RANGING, TELECOMMAND, AND TELEMETRY OPERATIONS

The CCSDS,

considering

(a) that two-way transmissions are generally employed for making range measurements to a distant spacecraft;

(b) that, for simultaneous telecommand and ranging on the earth-to-space link, the telecommand performance may suffer some degradation due to telecommand-ranging cross-modulation components;

(c) that, for simultaneous telemetry and ranging on the space-to-earth link, the telemetry performance may be degraded due to interference from the filtered versions of the uplink ranging, feed-through telecommand, cross-modulation components and noise;

(d) that the timing offset due to synchronous clocks between the telecommand and telemetry may cause serious telemetry bit error rate (BER) degradation when the two subcarriers are not separated in frequency sufficiently;

(e) that the performance degradation in the telecommand and telemetry due to the factors named in considerations in (b), (c) and (d) can be minimized if the modulation indices for telecommand, range, telemetry are chosen properly;

(f) that the ranging receiver is usually not susceptible to interference from unwanted emissions which fall outside the receiver’s bandwidth;

(g) that the selected modulation indices will provide the optimum power division between the data (telecommand/telemetry) and the ranging channels for a required ranging accuracy, and a specified bit error rate degradation in the data channel;

(h) that the selected modulation indices will result in adequate power for carrier tracking without degrading the specified data channel performance;

(i) that the selected modulation indices will provide the required link performance margins for the carrier, range and data signals;

recommends

that the CCSDS agencies utilize the technique illustrated in Annex 1 and Figure 4.1.1-1 to select the optimum set of modulation indices for simultaneous ranging, telecommand, and telemetry operations;

4.1.1 SELECTION OF OPTIMUM MODULATION INDICES FOR SIMULTANEOUS RANGING, TELECOMMAND, AND TELEMETRY OPERATIONS (Continued)

ANNEX 1

The constants A_1, A_2, A_3, A_4, A_5, and the design factor K shown in Figure 4.1.1-1 are defined as follows:

$$A_1 = \frac{(SNR)_D}{(SNR)_C}$$

$$A_2 = \frac{(SNR)_D}{(SNR)_R}$$

$$A_3 = \frac{(SNR)_R}{(SNR)_D} = \frac{1}{A_2}$$

$$A_4 = (SNR)_R$$

$$A_5\ (dB) = 10 \log_{10}[10^{\{\Delta_D(dB)/10\}} - 1]$$

$$K = \left[\frac{(SNR)_R}{(SNR)_D}\right] \times \left[\frac{1}{\Delta_s}\right]$$

where:

Δ_D (dB)	=	Degradation in the Data Channel due to the interference from the ranging channel.
Δ_s (dB)	=	A_5 (dB) - [$(SNR)_{REQ}$ + P_I (dB)]
$(SNR)_{REQ}$	=	Required data signal-to-noise ratio to achieved a desired bit error rate.
P_I	=	The maximum ranging channel power level which falls into the data channel.
$(SNR)_D$	=	Threshold signal-to-noise power density ratio in the data channel.
$(SNR)_C$	=	Threshold signal-to-noise power density ratio in the carrier channel.
$(SNR)_R$	=	Threshold signal-to-noise power density in the ranging channel.

4.1.1 SELECTION OF OPTIMUM MODULATION INDICES FOR SIMULTANEOUS RANGING, TELECOMMAND, AND TELEMETRY OPERATIONS (Continued)

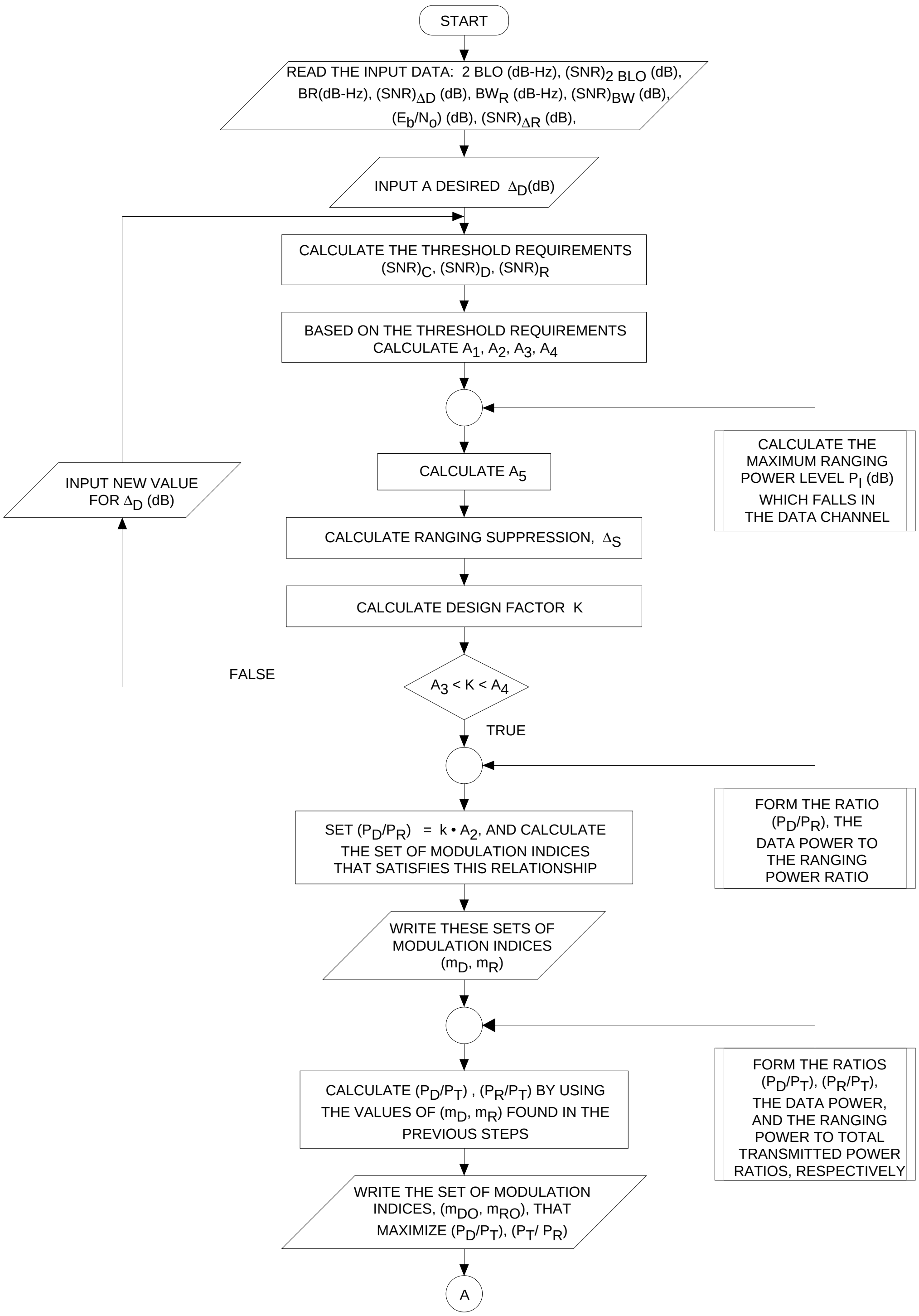
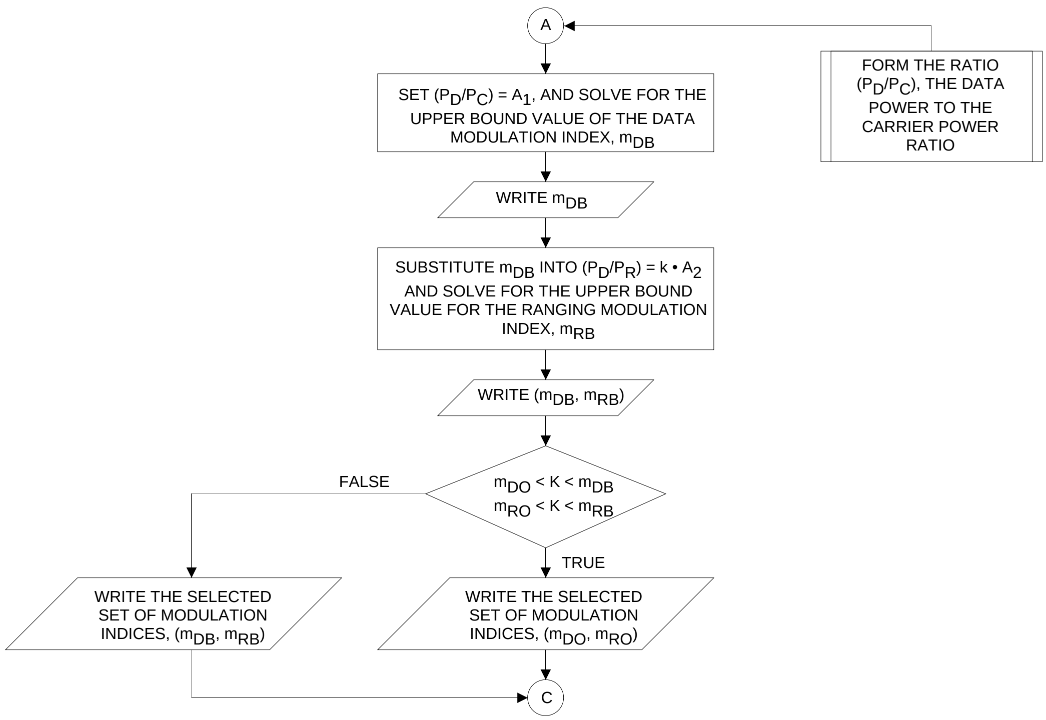


FIGURE 4.1.1-1: MT's ALGORITHM: AN ALGORITHM TO SEARCH FOR A SET OF OPTIMUM MODULATION INDICES FOR SIMULTANEOUS COMMAND/RANGE/ TELEMETRY OPERATIONS

4.1.1 SELECTION OF OPTIMUM MODULATION INDICES FOR SIMULTANEOUS RANGING, TELECOMMAND, AND TELEMETRY OPERATIONS (Continued)



LEGEND:

(E_b/N_o) (dB)	=	REQUIRED BIT SNR TO ACHIEVE A DESIRED BER IN dB
2 BLO(dB-Hz)	=	TWO-SIDED PLL NOISE BANDWIDTH IN dB-Hz
$(SNR)_{2\ BLO}$ (dB)	=	REQUIRED OPERATING THRESHOLD IN dB
BR(dB-Hz)	=	REQUIRED DATA BIT RATE IN dB-Hz
$(SNR)_{\Delta D}$ (dB)	=	SNR DEGRADATION DUE TO RECEIVER HARDWARE IN dB
BW_R(dB-Hz)	=	RANGING BANDWIDTH IN dB-Hz (2-SIDED)
$(SNR)_{BW}$ (dB)	=	REQUIRED RANGING SNR BWR, EXPRESSED IN dB
$(SNR)_{\Delta R}$ (dB)	=	SNR DEGRADATION DUE TO RANGING RECEIVER HARDWARE IN dB
Δ_S	=	RANGING SUPPRESSION RELATIVE TO DATA POWER LEVEL IN dB
K	=	DESIGN FACTOR
Δ_D(dB)	=	DEGRADATION IN THE DATA CHANNEL DUE TO THE INTERFERENCE FROM THE RANGING CHANNEL
m_D	=	DATA CHANNEL MODULATION INDEX IN RADIAN
m_R	=	RANGING CHANNEL MODULATION INDEX IN RADIAN
P_D	=	THE RECOVERABLE POWER IN THE FIRST-ORDER SIDEBAND OF THE DATA CHANNEL
P_R	=	THE RECOVERABLE POWER IN THE FIRST-ORDER SIDEBAND OF THE RANGING CHANNEL
P_T	=	TOTAL TRANSMITTED POWER
P_C	=	THE RECOVERABLE POWER IN THE CARRIER CHANNEL
CM_C	=	CALCULATED CARRIER PERFORMANCE MARGIN
DM_C	=	CALCULATED DATA PERFORMANCE MARGIN
RM_C	=	CALCULATED RANGING MARGIN
CM_{REQ}	=	REQUIRED CARRIER PERFORMANCE MARGIN
DM_{REQ}	=	REQUIRED DATA PERFORMANCE MARGIN
RM_{REQ}	=	REQUIRED RANGING PERFORMANCE MARGIN

FIGURE 4.1.1-1: MT's ALGORITHM: AN ALGORITHM TO SEARCH FOR A SET OF OPTIMUM MODULATION INDICES FOR SIMULTANEOUS COMMAND/RANGE/TELEMETRY OPERATIONS

4.1.1 SELECTION OF OPTIMUM MODULATION INDICES FOR SIMULTANEOUS RANGING, TELECOMMAND, AND TELEMETRY OPERATIONS (Continued)

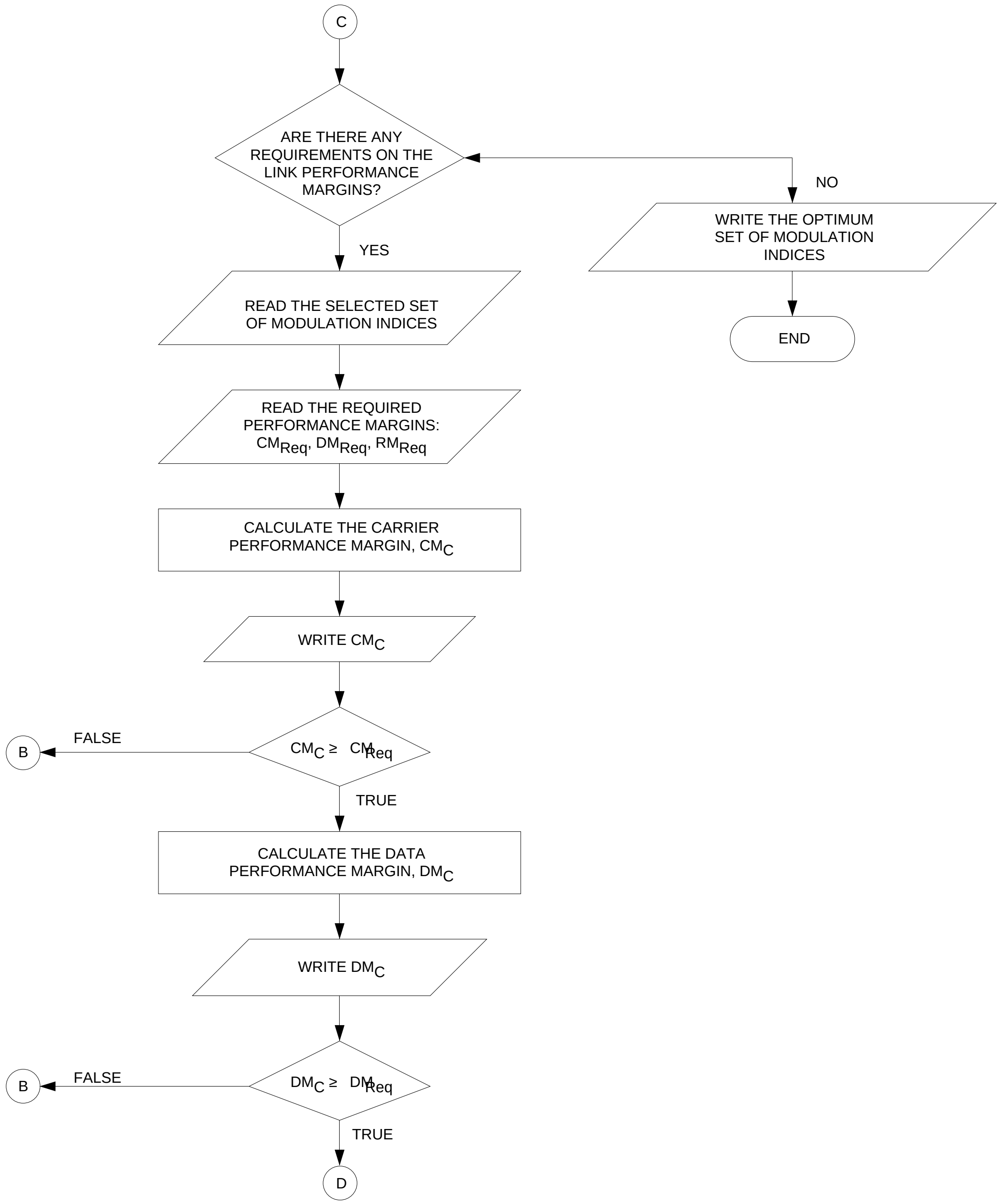


FIGURE 4.1.1-1: MT's ALGORITHM: AN ALGORITHM TO SEARCH FOR A SET OF OPTIMUM MODULATION INDICES FOR SIMULTANEOUS COMMAND/RANGE/TELEMETRY OPERATIONS

4.1.1 SELECTION OF OPTIMUM MODULATION INDICES FOR SIMULTANEOUS RANGING, TELECOMMAND, AND TELEMETRY OPERATIONS (Continued)

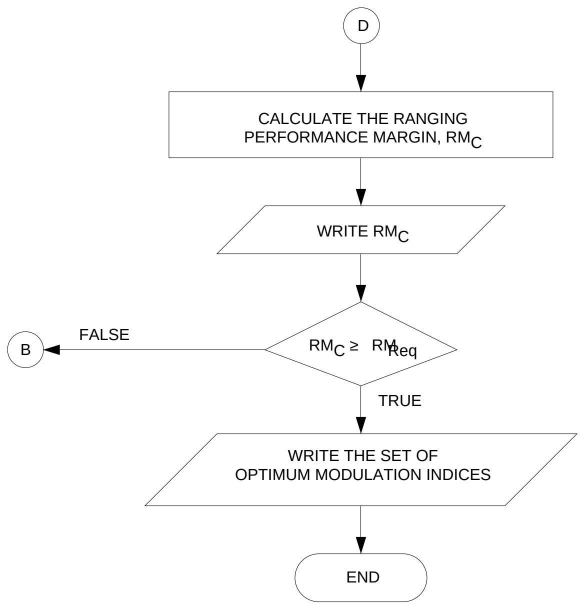


FIGURE 4.1.1-1: MT's ALGORITHM: AN ALGORITHM TO SEARCH FOR A SET OF OPTIMUM MODULATION INDICES FOR SIMULTANEOUS COMMAND/RANGE/TELEMETRY OPERATIONS

4.1.2 TELECOMMUNICATIONS LINK DESIGN CONTROL TABLE (Link and Weather Not Combined)

The CCSDS,

considering

(a) that an ability to exchange telecommunications link performance information is necessary for agencies to engage in cooperative space missions, conduct joint space ventures, and provide ground station cross support to another agency's spacecraft;

(b) that a uniform method for presenting link parameters and calculating link performance will facilitate the exchange of information;

(c) that a uniform Design Control Table (DCT) is a convenient method for displaying telecommunications link performance information;

(d) that the order in which the parameters are arranged in the Design Control Table can affect its clarity and the ease with which a signal can be traced through a telecommunications system;

(e) that nominal link parameter values, representing the expected performance by the link, are important to an understanding of the telecommunications system;

(f) that favorable and adverse tolerances on the nominal link parameter values are required to provide confidence in the link's performance;

recommends

(1) that the uniform Design Control Table, consisting of the general information and link performance pages contained in the Annex, be used as a means for comparing telecommunications link performance calculations between agencies;

(2) that in computing favorable and adverse tolerances on the nominal performance values, agencies should use 3-sigma values for the telecommand system and use 2-sigma values for all other systems.

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4.1.2 TELECOMMUNICATIONS LINK DESIGN CONTROL TABLE

CCSDS LINK DESIGN CONTROL TABLE
GENERAL INFORMATION
(Link and Weather Not Combined)

Page 1

1	Owner CCSDS Agency	
2	Name of Mission	
3	Name of Spacecraft	
4	Mission Category a. A = Alt.<2,000,000 km b. B = Alt.>2,000,000 km	
5	Link Budget Number	
6	Revision No. / Conditions	
7	Date	
8	File Name	
9	Project Cognizant Person Name: Title: Address: Telephone: Fax Number: Telemail/Telex No.:	
10	Network Cognizant Person Name: Address: Telephone: FAX No.: Telemail / Telex No.:	

4.1.2 TELECOMMUNICATIONS LINK DESIGN CONTROL TABLE (Continued)

CCSDS LINK DESIGN CONTROL TABLE
COMMUNICATIONS SYSTEM OPERATING CONDITIONS
(Link and Weather Not Combined)

Page 2

EARTH - SPACE - LINK			SPACE - EARTH - LINK		
E/S TRANSMITTING RF CHANNEL:			**S/C TRANSMITTING RF CHANNEL:**		
1	RF Carrier Modulation		11	RF Carrier Modulation	
	a. Ch 1 Type			a. Ch 1 Type	
	b. Ch 1 Format			b. Ch 1 Format	
	c. Ch 2 Type			c. Ch 2 Type	
	d. Ch 2 Format			d. Ch 2 Format	
E/S TRANSMITTING DATA CHANNEL:			**S/C TRANSMITTING DATA CHANNEL:**		
2	Baseband Data		12	Baseband Data	
	a. Ch 1 Bit Rate, b/s			a. Ch 1 Bit Rate, b/s	
	b. Ch 1 Bit Err Rate			b. Ch 1 Bit Err Rate	
	c. Ch 2 Bit Rate, b/s			c. Ch 2 Bit Rate, b/s	
	d. Ch 2 Bit Err Rate			d. Ch 2 Bit Err Rate	
3	Data Coding		13	Data Coding	
	a. Ch 1 Type			a. Ch 1 Rate	
	b. Ch 1 No. Info Bit			b. Ch 1 Constr Lngth	
	c. Ch 1 Block Length			c. Ch 1 Concat Code	
				d. Ch 1 Data/Tot Bit	
	d. Ch 2 Type			e. Ch 2 Rate	
	e. Ch 2 No. Info Bit			f. Ch 2 Constr Lngth	
	f. Ch 2 Block Length			g. Ch 2 Concat Code	
				h. Ch 2 Data/Tot Bit	
4	Subcarrier		14	Subcarrier	
	a. Ch 1 Waveform			a. Ch 1 Waveform	
	b. Ch 1 Frequency			b. Ch 1 Frequency	
	c. Ch 1 Mod Type			c. Ch 1 Mod Type	
	d. Ch 2 Waveform			d. Ch 2 Waveform	
	e. Ch 2 Frequency			e. Ch 2 Frequency	
	f. Ch 2 Mod Type			f. Ch 2 Mod Type	
E/S TRANSMITTING RNG CHANNEL:			**S/C - E/S RNG CHANNEL:**		
5	a. System Type		15	a. Code Regenerate	
	b. Tone/Code Wavfm			b. Coh Ops Reqd	
	c. Highest Frequency			c. Reqd Accuracy (m)	
	d. Lowest Frequency			d. Bandwidth T/C 1	
	e. Total Comp No.			e. Bandwidth T/C 2	
EARTH-TO-SPACE PATH PERFORMANCE:			**SPACE-TO-EARTH PATH PERFORMANCE:**		
6	a. Weather Avail		16	a. Weather Avail	
	b. S/C Distance (km)			b. S/C Distance (km)	

4.1.2 TELECOMMUNICATIONS LINK DESIGN CONTROL TABLE (Continued)

CCSDS LINK DESIGN CONTROL TABLE
EARTH - SPACE - LINK
INPUT DATA SHEET

Page 3

MISSION AND SPACECRAFT		UNITS	CHANNEL 1			CHANNEL 2		
			DESIGN VALUE	FAV TOL	ADV TOL	DESIGN VALUE	FAV TOL	ADV TOL
E/S TRANSMITTING RF CARRIER CHANNEL PARAMETERS:								
1	Transmitter Power	dBW						
2	Transmitter Frequency	MHz						
3	Ant. Gain	dBi						
4	Antenna Circuit Loss	dB						
5	Antenna Pointing Loss	dB						
E/S TRANSMITTING DATA CHANNEL PARAMETERS:								
6	Information Bit Rate	b/s						
7	Subcarrier Frequency	kHz						
8	Subcarrier Waveform	Sin-Sq						
9	RF Modulation Index	Rad-pk						
E/S TRANSMITTING RNG CHANNEL PARAMETERS:								
10	Simultaneous With Data	Yes-No						
11	Ranging Waveform	Sin-Sq						
12	a. Mod Index Tone/Code 1	Rad-pk						
	b. Mod Index Tone/Code 2	Rad-pk						
EARTH - TO - SPACE PATH PARAMETERS:								
13	Topocentric Range	km						
14	Atmospheric Attenuation	dB						
15	Ionospheric Loss	dB						
16	Antenna Elevation Angle	deg						
S/C RECEIVING RF CARRIER CHANNEL PARAMETERS:								
17	Antenna Gain	dBi						
18	Polarization Loss	dB						
19	Antenna Pointing Loss	dB						
20	Antenna Circuit Loss	dB						
21	Carrier Circuit Loss	dB						
22	Total Noise Temperature	K						
	a. Rcvr Operating Temp	K						
	b. Feed Through Noise	K						
	c. Hot Body Noise	K						
23	Threshold Loop Noise BW	Hz						
24	Reqd Thrshold SNR in 2 B_{LO}	dB						
S/C RECEIVING DATA CHANNEL PARAMETERS:								
25	Phase Jitter Loss	dB						
26	Demod / Detector Loss	dB						
27	Waveform Distortion Loss	dB						
28	Max Rng Interfer to Data	dB						
29	Reqd Data Eb/No	dB						
S/C RECEIVING RNG CHANNEL PARAMETERS:								
30	Ranging Demodulator Loss	dB						
31	Ranging Filter Bandwidth	MHz						
32	Reqd Tone/Code 1 SNR	dB						
33	Reqd Tone/Code 2 SNR	dB						

4.1.2 TELECOMMUNICATIONS LINK DESIGN CONTROL TABLE (Continued)

CCSDS LINK DESIGN CONTROL TABLE
SPACE - EARTH - LINK
INPUT DATA SHEET

Page 4

MISSION AND SPACECRAFT		UNITS	CHANNEL 1			CHANNEL 2		
			DESIGN VALUE	FAV TOL	ADV TOL	DESIGN VALUE	FAV TOL	ADV TOL
S/C TRANSMITTING RF CARRIER CHANNEL PARAMETERS:								
51	Transmitter Power	dBW						
52	Transmitter Frequency	MHz						
53	Antenna Gain	dBi						
54	Antenna Circuit Loss	dB						
55	Antenna Pointing Loss	dB						
S/C TRANSMITTING DATA CHANNEL PARAMETERS:								
56	Information Bit Rate	kb/s						
57	Subcarrier Frequency	kHz						
58	Subcarrier Waveform	Sin-Sq						
59	RF Modulation Index	Rad-pk						
S/C TRANSMITTING RNG CHANNEL PARAMETERS:								
60	Simultaneous With Data	Yes-No						
61	Mod Index Tone/Code	Rad-pk						
S/C - TO - EARTH PATH PARAMETERS:								
62	Topocentric Range	km						
63	Atmospheric Attenuation	dB						
64	Ionospheric Loss	dB						
65	Antenna Elevation Angle	deg						
E/S RECEIVING RF CARRIER CHANNEL PARAMETERS:								
66	Ant Gain	dBi						
67	Polarization Loss	dB						
68	Antenna Pointing Loss	dB						
69	Antenna Circuit Loss	dB						
70	Total Noise Temperature	K						
	a. Rcvr Operating Temp	K						
	b. Feed Through Noise	K						
	c. Hot Body Noise	K						
	d. Weather Temp Increase	K						
71	Threshold Loop Noise BW	Hz						
72	Reqd Threshold SNR in 2 B_{LO}	dB						
E/S RECEIVING DATA CHANNEL PARAMETERS:								
73	Phase Jitter Loss	dB						
74	Demod / Detector Loss	dB						
75	Waveform Distortion Loss	dB						
76	Max Rng Interfer to Data	dB						
77	Reqd Data Eb/No	dB						
E/S RECEIVING RNG CHANNEL PARAMETERS:								
78	Ranging Demodulator Loss	dB						
79	Reqd Tone/Code 1 Pwr/No	dB-Hz						
80	Reqd Tone/Code 2 Pwr/No	dB-Hz						

4.1.2 TELECOMMUNICATIONS LINK DESIGN CONTROL TABLE (Continued)

CCSDS LINK DESIGN CONTROL TABLE
EARTH - TO - SPACE LINK
LINK COMPUTATIONS
(Link and Weather Not Combined)

Page 5

MISSION AND SPACECRAFT		UNITS	DESIGN VALUE	MEAN VALUE	VARI-ANCE	PDF REF	REMARKS
E/S TRANSMITTING RF CARRIER CHANNEL PERFORMANCE:							
101	Transmitter Power	dBW					
102	Transmit Ant Gain [Effect]	dB					
103	Transmitting EIRP	dBW					
104	Trans Carrier Power	dBW					
105	Trans Carrier Power/PT	dB					
E/S TRANSMITTING DATA CHANNEL PERFORMANCE:							
106	Trans Ch 1 Data Power	dBW					
107	Trans Ch 1 Data Power/PT	dB					
108	Trans Ch 2 Data Power	dBW					
109	Trans Ch 2 Data Power/PT	dB					
E/S TRANSMITTING RNG CHANNEL PERFORMANCE:							
110	Tone - Code 1 Power	dBW					
111	Tone - Code 1 Power/PT	dB					
112	Tone - Code 2 Power	dBW					
113	Tone - Code 2 Power/PT	dB					
EARTH - TO - SPACE PATH PERFORMANCE:							
114	Free Space Loss	dB					
115	Atmospheric Attenuation	dB					
116	Ionospheric Loss	dB					
S/C RECEIVING RF CARRIER CHANNEL PERFORMANCE:							
117	Receiving Ant Gain [Effect]	dBi					
118	Noise Spectral Density	dBW/H z					
119	Threshold Loop BW, 2 B_{LO}	Hz					
120	Rcvd Carrier Power	dBW					
121	Carrier Performance Margin	dB					
S/C RECEIVING DATA CHANNEL PERFORMANCE:							
122	Ch 1 Data Loss Due to Rng	dB					
123	Rcvd Ch 1 Eb / No	dB					
124	Reqd Ch 1 Eb / No	dB					
125	Ch 1 Data Perform Margin	dB					
126	Ch 2 Data Loss Due to Rng	dB					
127	Rcvd Ch 2 Eb / No	dB					
128	Reqd Ch 2 Eb / No	dB					
129	Ch 2 Data Perform Margin	dB					
S/C RECEIVING RNG CHANNEL PERFORMANCE:							
130	Rcvd Code 1 Power / No	dB-Hz					
131	Rcvd Code 2 Power / No	dB-Hz					
132	Rcvd Total Rng Power / No	dB-Hz					
133	Ranging Margin	dB					

4.1.2 TELECOMMUNICATIONS LINK DESIGN CONTROL TABLE (Continued)

CCSDS LINK DESIGN CONTROL TABLE
SPACE - TO - EARTH LINK
LINK COMPUTATIONS
(Link and Weather Not Combined)

Page 6

MISSION AND SPACECRAFT		UNITS	DESIGN VALUE	MEAN VALUE	VARI-ANCE	PDF REF	REMARKS
S/C TRANSMITTING RF CARRIER CHANNEL PERFORMANCE:							
151	Transmitter Power	dBW					
152	Transmit Ant Gain [Effect]	dB					
153	Transmitting EIRP	dBW					
154	Trans Carrier Power	dBW					
155	Trans Carrier Power/PT	dB					
S/C TRANSMITTING DATA CHANNEL PERFORMANCE:							
156	Trans Ch 1 Data Power	dBW					
157	Trans Ch 1 Data Power/PT	dB					
158	Trans Ch 2 Data Power	dBW					
159	Trans Ch 2 Data Power/PT	dB					
S/C TRANSMITTING RNG CHANNEL PERFORMANCE:							
160	Tone - Code 1 Power	dBW					
161	Tone - Code 1 Power/PT	dB					
162	Tone - Code 2 Power	dBW					
163	Tone - Code 2 Power/PT	dB					
SPACE - TO - EARTH PATH PERFORMANCE:							
164	Free Space Loss	dB					
165	Atmospheric Attenuation	dB					
166	Ionospheric Loss	dB					
E/S RECEIVING RF CARRIER CHANNEL PERFORMANCE:							
167	Receiving Ant Gain [Effect]	dBi					
168	Noise Spectral Density	dBW/H z					
169	Threshold Loop BW, 2 B_{LO}	Hz					
170	Rcvd Carrier Power	dBW					
171	Carrier Performance Margin	dB					
E/S STATION RECEIVING DATA CHANNEL PERFORMANCE:							
172	Ch 1 Data Loss Due to Rng	dB					
173	Rcvd Ch 1 Eb / No	dB					
174	Reqd Ch 1 Eb / No	dB					
175	Ch 1 Data Perform Margin	dB					
176	Ch 2 Data Loss Due to Rng	dB					
177	Rcvd Ch 2 Eb / No	dB					
178	Reqd Ch 2 Eb / No	dB					
179	Ch 2 Data Perform Margin	dB					
E/S STATION RECEIVING RNG CHANNEL PERFORMANCE:							
180	Rcvd Code 1 Power / No	dB-Hz					
181	Rcvd Code 2 Power / No	dB-Hz					
182	Rcvd Total Rng Power / No	dB-Hz					
183	Ranging Margin	dB					

4.1.2 TELECOMMUNICATIONS LINK DESIGN CONTROL TABLE (Continued)

EXPLANATION OF THE REMARKS :::

1	DESIGN TRANSMITTED CARRIER POWER (dBW) IS COMPUTED BY USING DESIGN VALUE OF Pc/Pt AND THE EIRP. THE DESIGN VALUE OF Pc/Pt IS COMPUTED BY USING THE DESIGN VALUES OF MOD INDICES.
2	MEAN TRANSMITTED CARRIER POWER (dBW) IS COMPUTED BY USING FAV AND ADV TOLERANCE OF Pc/Pt AND THE EIRP. THESE TOLERANCES ARE COMPUTED USING ALL POSSIBLE COMBINATIONS Of THE MOD IND. VARIANCE OF TRANS CARRIER POWER (dBW) IS COMPUTED BY USING EIRP AND THE FAV AND ADV TOLERANCES OF Pc/Pt. TOLERANCES ARE COMPUTED BY USING ALL POSSIBLE MOD INDEX COMBINATIONS.
2A	A TRIANGULAR DENSITY USED IS FOR THE Pc/Pt RATIO.
3	DESIGN TRANSMITTED CARRIER POWER (dBW) IS COMPUTED BY USING DESIGN VALUE OF Pd/Pt AND THE EIRP. DESIGN VALUE OF Pd/Pt IS COMPUTED BY USING THE DESIGN VALUES Of MOD INDICES.
4	MEAN TRANSMITTED DATA POWER (dBW) IS COMPUTED BY USING FAV AND ADV TOLERANCE OF Pd/Pt AND THE EIRP. THESE TOLERANCES ARE COMPUTED USING ALL POSSIBLE MOD INDEX COMBINATIONS. VARIANCE OF TRANS DATA POWER (dBW) IS COMPUTED BY USING EIRP AND THE FAV AND ADV TOLERANCE OF Pd/Pt. TOLERANCES ARE COMPUTED USING ALL POSSIBLE MOD INDEX COMBINATIONS.
4A	A TRIANGULAR DENSITY USED IS FOR THE Pd/Pt RATIO.
5	DESIGN TRANSMITTED RANGE POWER (dBW) IS COMPUTED USING DESIGN VALUE OF Pr/Pt AND THE EIRP. DESIGN VALUE OF Pr/Pt IS COMPUTED USING THE DESIGN VALUES OF MOD INDICES.
6	MEAN TRANSMITTED RANGE POWER (dBW) IS COMPUTED USING FAV AND ADV TOLERANCE OF Pr/Pt AND THE EIRP. TOLERANCES ARE COMPUTED BY USING ALL POSSIBLE MOD INDEX COMBINATIONS. VARIANCE OF TRANS RANGE POWER (dBW) IS COMPUTED USING EIRP AND THE FAV AND ADV TOLERANCE OF Pr/Pt. TOLERANCES ARE COMPUTED USING ALL POSSIBLE MOD INDEX COMBINATIONS.
6A	A TRIANGULAR DENSITY USED IS FOR THE Pr/Pt RATIO.
7	THE SPACE LOSS USING FAVORABLE TOLERANCE.
8	THE SPACE LOSS USING ADVERSE TOLERANCE.
9	LINK AND ATMOSPHERICS ARE ASSUMED TO BE INDEPENDENT. THIS IS THE WORST CASE. MEAN AND VARIANCE ARE COMPUTED USING THE APPROPRIATE WEATHER MODEL.
10	SAME AS REMARK 1 BUT APPLIED FOR THE DOWNLINK.
11	SAME AS REMARK 2 BUT APPLIED FOR THE DOWNLINK.
11A	SAME AS REMARK 2a BUT APPLIED FOR THE DOWNLINK.
12	SAME AS REMARK 3 BUT APPLIED FOR THE DOWNLINK.
13	SAME AS REMARK 4 BUT APPLIED FOR THE DOWNLINK.
13A	SAME AS REMARK 4a BUT APPLIED FOR THE DOWNLINK.
14	SAME AS REMARK 5 BUT APPLIED FOR THE DOWNLINK.
15	SAME AS REMARK 6 BUT APPLIED FOR THE DOWNLINK.
15A	SAME AS REMARK 6a BUT APPLIED FOR THE DOWNLINK.
16	SAME AS REMARK 7 BUT APPLIED FOR THE DOWNLINK.
17	SAME AS REMARK 8 BUT APPLIED FOR THE DOWNLINK.
18	SAME AS REMARK 9 BUT APPLIED FOR THE DOWNLINK.

4.1.2 TELECOMMUNICATIONS LINK DESIGN CONTROL TABLE (Continued)

NOTES::::::

UPLINK:

1. REQUIRED TONE 1 SNR MEANS THE REQUIRED TONE / CODE 1 RANGING POWER DIVIDED BY THE NOISE POWER IN THE RANGING BANDWIDTH. THE USER IS EXPECTED TO INPUT THE SNR VALUE IN SHEET 3, LINE 32.
2. WHEN THE RANGING MARGIN IS COMPUTED, THE RANGING BANDWIDTH IS USED TO CONVERT THE REQUIRED POWER-TO-NOISE DENSITY RATIO AND, THEREAFTER, IT IS COMPARED WITH THE RECEIVED RANGING POWER-TO-NOISE DENSITY RATIO.

DOWNLINK:

1. REQUIRED RANGING POWER-TO-NOISE DENSITY RATIO IS TO BE SPECIFIED TO PROVIDE THE NEEDED RANGING ACCURACY. THE STEPS ARE:
   a. SPECIFY INTEGRATION TIME NEEDED MEET ACCURACY REQUIREMENTS.
   b. COMPUTE EFFECTIVE BANDWIDTH (e.g., 1/INTEGRATION TIME).
   c. USING CURVES IN TRK-30 Of DSN DOCUMENT 810-5, FIND REQUIRED Pr/No AND ENTER ON SHEET 4, LINE 79.
      DENSITY RATIO AND PROVIDE THIS IN SHEET 4 PLACE 79
2. RANGING MARGIN IS BASED ON EFFECTIVE BANDWIDTH COMPUTED ABOVE.

4.1.3 STANDARD TERMINOLOGY FOR TELECOMMUNICATIONS LINK PERFORMANCE CALCULATIONS

The CCSDS,

considering

(a) that a uniform method for computing telecommunications link performance is desirable in order to facilitate the exchange of information among agencies;

(b) that it is necessary to agree upon the definitions of certain key terms before a uniform method for computing telecommunications link performance can be adopted;

(c) that definitions which have been adopted by internationally recognized organizations for such key terms should be used whenever possible;

recommends

(1) that the terms listed in Article 1 of the Radio Regulations and in the Annex below be used together with the meaning ascribed to them in the corresponding definition.

(2) that the telecommunications link, together with the noise sources and losses, be described as shown in Figure 4.1.3-1.

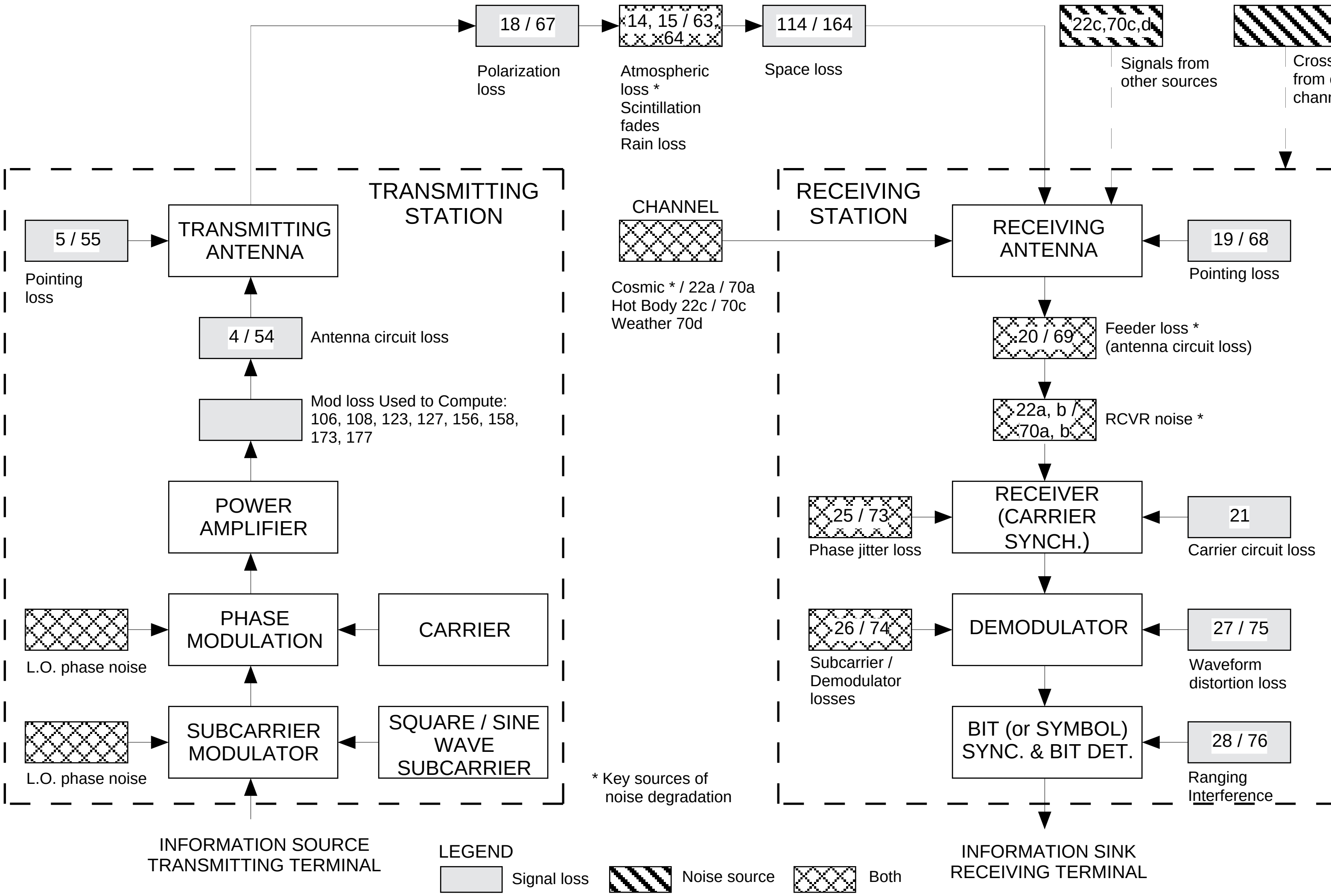

Figure 4.1.3-1: Typical Space Communications Link Showing Loss and Noise Sources

4.1.3 ANNEX AID RECOMMENDATION

TELECOMMUNICATIONS LINK DESIGN CONTROL TABLE (Link and Weather Not Combined): A set of informational and input data tables for the user to provide the salient earth-to-space and space-to-earth telecommunications equipment and link characteristics together with tables containing the computed performance of these links without regard to weather induced effects.

GENERAL INFORMATION

(1) *OWNER CCSDS AGENCY*: The CCSDS member agency having primary responsibility for the success or failure of the mission.

(2) *NAME OF MISSION*: The name given to the mission by the CCSDS member agency owner.

(3) *NAME OF SPACECRAFT*: The name given to a specific spacecraft, which is part of the named mission, by the CCSDS member agency owner.

(4) *MISSION CATEGORY*: The mission's category, either Category B for deep space missions (missions whose altitude above the earth's surface exceeds 2 x 10^6 km) or Category A for non-deep space missions (those whose altitude above the earth's surface are less than, or equal to, 2 x 10^6 km).

(5) *LINK BUDGET NUMBER*: A number which is assigned to this link budget study under the conditions and with the configuration stated on the following pages to distinguish it from other such studies.

(6) *REVISION NO/CONDITIONS*: The most recent revision of this telecommunications link budget study, which is contained in this table, for the named spacecraft and mission together with a short description of the study conditions (e.g., transmitter power, station used, etc.).

(7) *DATE*: The date that this study or revision was made.

(8) *FILE NAME*: The name or number of the file, whether on a computer disk or other media, where this DCT is stored.

(9) *PROJECT COGNIZANT PERSON*:

Name: The name of the person in the owner agency with whom inputs to, or outputs from this Design Control Table should be discussed and approved.

Title: The position or title of the person named in above.

Address: The full agency center's name and address which is required to contact the cognizant person in an efficient manner.

Telephone: The telephone number, including country and area codes of the cognizant person.

FAX Number: The FAX number, including country and area codes of the cognizant person.

Telemail/Telex No.: The full Telemail box name, including the relevant node, and/or the Telex number of the cognizant person.

4.13 ANNEX TO RECOMMENDATION (Continued)

GENERAL INFORMATION (Continued)

(10) *NETWORK COGNIZANT PERSON*:

Name: The name of the person in the agency operating the supporting network with whom inputs to, or outputs from this Design Control Table should be discussed and approved.

Address: The full network agency center's name and address which is required to contact the cognizant person in an efficient manner.

Telephone: The telephone number, including country and area codes of the cognizant person.

FAX Number: The FAX number, including country and area codes of the cognizant person.

Telemail/Telex No.: The full Telemail box name, including the relevant node, and/or the Telex number of the cognizant person.

4.1.3 ANNEX TO RECOMMENDATION (Continued)

COMMUNICATIONS SYSTEM OPERATING CONDITIONS

EARTH-TO-SPACE LINK

EARTH STATION (E/S) TRANSMITTING RF CHANNEL

(1) *RF CARRIER MODULATION*:

(1a) *Ch 1 Type*: The earth station's carrier modulation method. Generally, only phase modulation is recommended by the CCSDS for the RF carrier.

(1b) *Ch 1 Format*: The method used in the earth station to represent the modulated Telecommand symbols on the carrier (e.g., NRZ-L, NRZ-M, SP-L, etc.).

(1c) *Ch 2 Type*: Same definition as (1a) above except that it is applicable to RF channel 2.

(1d) *Ch 2 Format*: Same definition as (1b) above except that it is applicable to RF channel 2.

EARTH STATION (E/S) TRANSMITTING DATA CHANNEL

(2) BASEBAND DATA:

(2a) *Ch 1 Bit Rate, b/s*: The rate, usually the maximum, at which uncoded telecommand or other data on channel 1 is to be transmitted from the earth station and for which the link performance is to be evaluated, expressed in b/s.

(2b) *Ch 1 Bit Err Rate*: The maximum information bit error rate providing acceptable performance for data channel 1 under consideration, expressed as a dimensionless fraction less than 0.5.

(2c) *Ch 2 Bit Rate, b/s*: Same definition as (2a) above except that it is applicable to channel 2.

(2d) *Ch 2 Bit Err Rate*: Same definition as (2b) above except that it is applicable to channel 2.

(3) *DATA CODING*:

(3a) *Ch 1 Type*: The type or name (e.g., block, Reed-Solomon, etc.) of the error detecting-correcting code used on data channel 1 by the earth station.

(3b) *Ch 1 No. Info Bit*: The number of information bits contained in a block code on data channel 1 which is transmitted from the earth station, expressed as a number.

(3c) *Ch 1 Block Length*: The total length of the block used on data channel 1 from the earth station, expressed as a number.

(3d) *Ch 2 Type*: Same definition as (3a) above except that it is applicable to data channel 2.

4.1.3 ANNEX TO RECOMMENDATION (Continued)

(3e) *Ch 2 No. Info Bit*: Same definition as (3b) above except that it is applicable to channel 2.

(3f) *Ch 2 Block Length*: Same definition as (3c) above except that it is applicable to channel 2.

(4) *SUBCARRIER*:

(4a) *Ch 1 Waveform*: The earth station's subcarrier waveform on data channel 1. Sine wave subcarriers are recommended by the CCSDS for telecommand.

(4b) *Ch 1 Frequency*: The earth station's subcarrier frequency on data channel 1, expressed in kHz.

(4c) *Ch 1 Mod Type*: The method used by the earth station for modulating the subcarrier with the data. PSK modulation is recommended by the CCSDS for telecommand subcarriers.

(4d) *Ch 2 Waveform*: Same definition as (4a) except that it is applicable to channel 2.

(4e) *Ch 2 Frequency*: Same definition as (4b) above except that it is applicable to channel 2.

(4f) *Ch 2 Mod Type*: Same definition as (4c) above except that it is applicable to channel 2.

EARTH STATION (E/S) TRANSMITTING RNG CHANNEL

(5a) *System Type*: The name, or descriptive term used to identify the specific ranging equipment (e.g., sidetone, square wave, DLR sine wave, CNES sine wave, ESA sine wave, DSN square wave, etc.).

(5b) *Tone/Code Wavfm*: The ranging tone or code waveform (e.g., sine or square).

(5c) *Highest Frequency*: The highest ranging tone or code frequency to be used for this mission, expressed in kHz.

(5d) *Lowest Frequency*: The lowest ranging tone or code frequency to be used for this mission, expressed in kHz.

(5e) *Tot Comp No*. The total number of ranging tone or code components which will be used in measuring the range, expressed as a number.

EARTH-TO-SPACE PATH PERFORMANCE

(6a) *Weather Avail*: The amount of time that the earth-to-space link must be available when considering the degradation due to weather, expressed as a percent.

(6b) *S/C Distance (km)*: The distance, measured along a ray path, between the earth station transmitting antenna's radiation point and the spacecraft receiving antenna's reference point, expressed in kilometers (km).

4.13 ANNEX TO RECOMMENDATION (Continued)

COMMUNICATIONS SYSTEM OPERATING CONDITIONS (Cont.)

SPACE-TO-EARTH LINK

SPACECRAFT (S/C) TRANSMITTING RF CHANNEL

(11) *RF CARRIER MODULATION*:

(11a) *Ch 1 Type*: The spacecraft's carrier modulation method. Generally, only phase modulation is recommended by the CCSDS for the RF carrier.

(11b) *Ch 1 Format*: The method used by the spacecraft to represent the modulated Telemetry symbols on the carrier (e.g., NRZ-L, NRZ-M, SP-L, etc.).

(11c) *Ch 2 Type*: Same definition as (11a) above except that it is applicable to RF channel 2.

(11d) *Ch 2 Format*: Same definition as (11b) above except that it is applicable to RF channel 2.

SPACECRAFT (S/C) TRANSMITTING DATA CHANNEL

(12) *BASEBAND DATA*:

(12a) *Ch 1 Bit Rate, b/s*: The rate, usually the maximum, at which uncoded telemetry or other data on channel 1 is to be transmitted from the spacecraft and for which the link performance is to be evaluated, expressed in b/s.

(12b) *Ch 1 Bit Err Rate*: The maximum information bit error rate providing acceptable performance for data channel 1 under consideration, expressed as a dimensionless fraction less than 0.5.

(12c) *Ch 2 Bit Rate, b/s*: Same definition as (12a) above except that it is applicable to channel 2.

(12d) *Ch 2 Bit Err Rate*: Same definition as (12b) above except that it is applicable to channel 2.

(13) *DATA CODING*:

(13a) *Ch 1 Rate*: The number of data bits compared the total number of convolutionally encoded symbols transmitted from the spacecraft, generally expressed as a fraction (e.g., 1/2 for the CCSDS recommended code).

(13b) *Ch 1 Constr Lngth*: The constraint length of the convolutional encoder on the spacecraft, expressed as a number (e.g., 7 for the CCSDS recommended code).

(13c) *Ch 1 Concat Code*: The type or name of the code which is concatenated with the convolutional code on the spacecraft (e.g., Reed-Solomon, Golay, block, etc.). The CCSDS recommends Reed-Solomon.

4.13 ANNEX TO RECOMMENDATION (Continued)

(13d) *Ch 1 Data/Tot Bit*: The number of data bits to total bits in a spacecraft block code, expressed as a ratio (e.g., 223/255 for the CCSDS recommended Reed-Solomon code).

(13e) *Ch 2 Rate*: Same definition as (13a) above except that it is applicable to channel 2.

(13f) *Ch 2 Constr Length*: Same definition as (13b) above except that it is applicable to channel 2.

(13g) *Ch 2 Concat Code*: Same definition as (13c) above except that it is applicable to channel 2.

(13h) *Ch 2 Data/Tot Bit*: Same definition as (13d) above except that it is applicable to channel 2.

(14) SUBCARRIER:

(14a) *Ch 1 Waveform*: The spacecraft's subcarrier waveform on data channel 1 (e.g., sine or square).

(14b) *Ch 1 Frequency*: The spacecraft's subcarrier frequency on data channel 1, expressed in kHz.

(14c) *Ch 1 Mod Type*: The spacecraft's method used for modulating the subcarrier with the data. PSK modulation is recommended by the CCSDS for telemetry subcarriers.

(14d) *Ch 2 Waveform*: Same definition as (14a) above except that it is applicable to channel 2.

(14e) *Ch 2 Frequency*: Same definition as (14b) above except that it is applicable to channel 2.

(14f) *Ch 2 Mod Type*: Same definition as (14c) above except that it is applicable to data channel 2.

SPACECRAFT (S/C) - EARTH STATION (E/S) RNG CHANNEL

(15a) *Code Regenerate*: A statement (Yes or No) indicating whether the spacecraft regenerates the ranging code prior to transmitting it to the earth station.

(15b) *Coh Ops Reqd*: A statement (Yes or No) indicating whether the earth station's ranging equipment requires a coherent spacecraft RF channel.

(15c) *Reqd Accuracy (m)*: The required ranging measurement accuracy, expressed in meters.

(15d) *Bandwidth T/C 1*: The earth station's effective bandwidth (1/integration time) required to obtain the ranging measurement accuracy stated in 5c, above, with the P_r/N_o stated on the Input Data Sheet, expressed in Hz.

(15e) *Bandwidth T/C 2*: The earth station's effective bandwidth (1/integration time) required to obtain the required probability of success in the ranging measurement, expressed in Hz.

4.1.3 ANNEX TO RECOMMENDATION (Continued)

SPACE-TO-EARTH PATH PERFORMANCE

(16a) *Weather Avail*: The amount of time that the space-to-earth link must be available when considering the degradation due to weather, expressed as a percent.

(16b) *S/C Distance (km)*: The distance, measured along a ray path, between the spacecraft transmitting antenna's radiation point and the earth station receiving antenna's reference point, expressed in kilometers (km).

4.1.3 ANNEX TO RECOMMENDATION (Continued)

INPUT DATA SHEET FOR EARTH-TO-SPACE LINK

EARTH STATION (E/S) TRANSMITTING RF CARRIER CHANNEL PARAMETERS

(1) *TRANSMITTER POWER*: That power actually produced at the transmitter power amplifier's output terminals, expressed as a positive or negative value in dBW (10 Log_{10} [Watts]).

(2) *TRANSMITTER FREQUENCY*: The unmodulated transmitter carrier frequency, expressed in Megahertz (MHz).

(3) *ANT GAIN (ITU/RR/154)*: "The ratio, usually expressed in decibels, of the power required at the input of a loss-free reference antenna to the power supplied to the input of the given antenna to produce, in a given direction, the same field strength or power flux-density at the same distance. When not specified otherwise, the gain refers to the direction of maximum radiation." In this application, the reference antenna is an isotropic antenna located in free space. The gain of the subject antenna is expressed as a positive or negative value in dBi.

Placing the network's name (e.g., DSN) in the box to the right of Antenna Gain and the antenna's diameter (e.g., 70) in box to the right of the network in row 3 will cause the computer program to consult its data base for all required information regarding that station.

(4) *ANTENNA CIRCUIT LOSS*: The attenuation in rf power occurring between the output terminals of the transmitting power amplifier and the point of electromagnetic radiation from that antenna, expressed as a negative value in dB.

(5) *ANTENNA POINTING LOSS*: The reduction in signal power at the receiving antenna resulting from imperfect pointing of the transmitting antenna such that the actual ray path from transmitting antenna to receiving antenna differs from the optimum ray path containing the point of maximum transmitting antenna gain, expressed as a negative value in dB.

EARTH STATION (E/S) TRANSMITTING DATA CHANNEL PARAMETERS

(6) *INFORMATION BIT RATE*: The rate at which uncoded Telecommand information bits are to be sent from the transmitting station to the receiving station, expressed in bits per second (b/s).

(7) *SUBCARRIER FREQUENCY*: The unmodulated Telecommand subcarrier's frequency, either 8 kHz or 16 kHz, expressed in kHz.

(8) *SUBCARRIER WAVEFORM*: The Telecommand subcarrier's waveform is always sine wave.

(9) *RF MODULATION INDEX*: The angle by which the rf carrier is phase shifted, with respect to the unmodulated rf carrier, as a result of the data on Telecommand channel of the modulator, expressed in radians peak.

4.1.3 ANNEX TO RECOMMENDATION (Continued)

EARTH STATION (E/S) TRANSMITTING RANGING CHANNEL PARAMETERS

(10) *SIMULTANEOUS WITH DATA*: A statement showing whether the computed performance is based upon simultaneous ranging and telecommanding operations (e.g., Yes or No).

(11) *RANGING WAVEFORM*: The waveform of the ranging modulation, sine wave for tone modulation, square wave for code modulation, expressed as Sin or Sq.

(12a) *MOD INDEX TONE / CODE 1*: The angle by which the rf carrier is phase shifted, with respect to the unmodulated rf carrier, as a result of the highest frequency (major) ranging Tone / Code modulation, expressed in radians peak (Rad-pk).

(12b) *MOD INDEX TONE / CODE 2*: The angle by which the rf carrier is phase shifted, with respect to the unmodulated rf carrier, as a result of the lower frequency (minor) ranging Tones / Codes modulation, expressed in radians peak (Rad-pk).

EARTH-TO-SPACE PATH PARAMETERS

(13) *TOPOCENTRIC RANGE*: The distance, measured along a ray path, between the earth station transmitting antenna’s radiation point and the spacecraft receiving antenna’s reference point, expressed in kilometers (km).

(14) *ATMOSPHERIC ATTENUATION*: The reduction in signal power at the receiving antenna, considering such factors as the earth station’s antenna elevation angle, weather, and geographical location, which results from absorption, reflection, and scattering of the rf signal as it passes through the Earth’s atmosphere, expressed as a negative value in dB.

(15) *IONOSPHERIC LOSS*: The reduction in signal power at the receiving antenna, considering such factors as the earth station’s elevation angle and communication’s frequency, resulting from the dispersive loss in radiated signal as it passes through the Ionosphere of the Earth and/or other bodies, expressed as a negative value in dB.

(16) *ANTENNA ELEVATION ANGLE*: The angle between a ray, representing the boresight of the earth-station’s antenna beam pattern, and a locally horizontal line, when both ray and line are contained in a vertical plane which also contains the center of the earth, expressed in degrees (deg).

SPACECRAFT (S/C) RECEIVING CARRIER RF CHANNEL PARAMETERS

(17) *ANTENNA GAIN*: The ratio of the power flux density required at the input of a loss-free isotropic antenna to that power flux density needed at the input of the spacecraft’s receiving antenna which produces the same output at the antenna’s terminals for a source which is at equal distance from both antennas. The gain of the spacecraft’s receiving antenna refers to the direction of maximum sensitivity, except in the case of a non-directional antenna in which case the gain refers to a minimum value corresponding to the antenna’s specified coverage. The gain of the subject antenna, at the receiving frequency, is expressed as a positive or negative value in dBi.

4.1.3 ANNEX TO RECOMMENDATION (Continued)

(18) *POLARIZATION LOSS*: The reduction in transferred signal power between transmitting and receiving stations resulting from differences in the radiated and received polarization patterns between the two antennas, expressed as a negative value in dB.

(19) *ANTENNA POINTING LOSS*: Same definition as (5) above except that it is applicable to the pointing error of the spacecraft's receiving antenna, expressed as a negative value in dB.

(20) *ANTENNA CIRCUIT LOSS*: The attenuation in rf power occurring between the point of electromagnetic radiation on the spacecraft's antenna and the input terminals of the low noise amplifier, expressed as a negative value in dB.

(21) *CARRIER CIRCUIT LOSS*: The sum of resistive (cable and circuitry), transmission line mismatches, and other implementation losses, expressed as a negative value in dB.

(22) *TOTAL NOISE TEMPERATURE*: The sum of the following noise temperature components (a) + (b) + (c), expressed in dBK. ***This sum is a computed entry and is <u>not</u> supplied by the user.***

(a) *Rcvr Operating Temp*: Overall Noise Temperature (CCIR/Rec 573-1): "For an antenna, or a receiving system including the antenna, the value to which the temperature of the resistive component of the source impedance should be brought, if it were the only source of noise, to cause the noise power at the output of the receiver to be the same as in real case."

In the Link Design Control Table, this parameter represents a receiving system reference temperature, at the received frequency, which excludes all contributions enumerated in (b), and (c), below, expressed in Kelvin. The reference temperature is measured at the input to the low-noise amplifier with the antenna viewing a cold sky background and which includes contributions from the: 1) cosmic background; 2) low noise amplifier and/or receiver; 3) circuit losses before the low-noise amplifier and/or receiver.

(b) *Feed Through Noise*: The increase in the receiver's operating temperature resulting from a portion of the transmitted signal leaking into the receiver's low-noise amplifier, expressed in Kelvin (K).

(c) *Hot Body Noise*: The predicted increase from the reference temperature (Tr), resulting from the receiving antenna being directed toward a body having a temperature greater than that of the cold sky reference, expressed in Kelvin (K).

(23) *THRESHOLD LOOP NOISE BW*: The total (2-sided) bandwidth of the rf carrier's phase-locked-loop, measured at the point when the SNR in that phase-locked-loop is +10 dB (carrier threshold), expressed in Hz.

(24) *REQD THRSHLD SNR IN 2 B_{LO}*: The ratio of received carrier power in 2 B_{LO} to the noise power density required to maintain receiver lock at threshold which has been defined to be +10 dB, expressed as a positive or negative value in dB.

4.1.3 ANNEX TO RECOMMENDATION (Continued)

SPACECRAFT (S/C) RECEIVING DATA CHANNEL PARAMETERS

(25) *PHASE JITTER LOSS*: The loss in symbol detection efficiency resulting from phase noise on the received rf carrier, which produces a non-orthogonal, noisy phase relationship between the demodulator's reference and the rf carrier to be demodulated, plus losses from the partial tracking of the modulated symbols by the rf carrier phase locked loop, expressed as a negative value in dB.

(26) *DEMOD / DETECTOR LOSS*: The loss in data demodulation and detection efficiency resulting from phase noise on the demodulated subcarrier, which produces a non-orthogonal, noisy phase relationship between the demodulator's reference and the subcarrier to be demodulated, plus losses from the partial tracking of the data bits by the subcarrier loop, plus losses due to timing errors in the symbol synchronizer's tracking loop, plus losses from nonlinearities in the demodulator, which reduce the device's efficiency, expressed as a negative value in dB.

(27) *WAVEFORM DISTORTION LOSS*: The loss in the recovered data signal power resulting from distortion in the modulated signal's (subcarrier and data) waveform, which has been introduced by filtering and non-linearities in the data channel or medium, expressed as a negative value in dB.

(28) *MAX RNG INTERFER TO DATA*: The ratio of the ranging modulation's maximum spectral power level, lying within the data spectrum bandwidth [*data spectrum bandwidth equals the data symbol rate in Hz*], to the total ranging power level, expressed as a negative value in dB.

(29) *REQD DATA* E_b / N_o: The energy per data bit divided by the noise spectral density which is required to obtain the stated Bit Error Rate, considering the improvement due to coding, expressed in dB.

SPACECRAFT (S/C) RECEIVING RANGING CHANNEL PARAMETERS

(30) *RANGING DEMODULATOR LOSS*: The loss in ranging demodulation and detection efficiency resulting from phase noise on the demodulated subcarrier, which produces a non-orthogonal, noisy phase relationship between the demodulator's reference and the i.f. carrier to be demodulated, plus losses from non-linearities in the demodulator, which reduce the device's efficiency, expressed as a negative value in dB.

(31) *RANGING FILTER BAND WIDTH*: The bandwidth of the ranging channel filter in the spacecraft receiver, expressed in Megahertz (MHz).

(32) *REQD TONE/CODE 1 SNR*: The ranging tone/code 1 signal-to-noise ratio required in the spacecraft's transponder to achieve the desired ranging measurement accuracy, expressed as a positive or negative number in dB.

(33) *REQD TONE/CODE 2 SNR*: The ranging tone/code 2 signal-to-noise ratio required in the spacecraft's transponder to achieve the desired ranging ambiguity resolution, expressed as a positive or negative number in dB.

4.1.3 ANNEX TO RECOMMENDATION (Continued)

INPUT DATA SHEET FOR SPACE-TO-EARTH LINK

SPACECRAFT (S/C) TRANSMITTING RF CARRIER CHANNEL PARAMETERS

(51) *TRANSMITTER POWER*: That power actually produced at the transmitter power amplifier's output terminals, expressed as a positive or negative value in dBW ($10Log_{10}$ [Watts]).

(52) *TRANSMITTER FREQUENCY*: The unmodulated transmitter carrier frequency, expressed in Megahertz.

(53) *ANTENNA GAIN*: The ratio of the power required at the input terminals of a loss-free isotropic antenna to the power supplied to the input terminals of the spacecraft's transmitting antenna which is needed to produce, in a specified direction, the same field strength (power flux density at an equivalent distance). The gain refers to the direction of maximum radiation except for non-directional antennas, in which case, the gain refers to a minimum value corresponding to the specified antenna coverage. The gain of the subject antenna, at the transmitting frequency, is expressed as a positive or negative value in dBi.

(54) *ANTENNA CIRCUIT LOSS*: The attenuation in rf power occurring between the output terminals of the transmitting power amplifier and the point of electromagnetic radiation from that antenna, expressed as a negative value in dB.

(55) *ANTENNA POINTING LOSS*: The reduction in signal power at the receiving antenna resulting from imperfect pointing of the transmitting antenna such that the actual ray path from transmitting antenna to receiving antenna differs from the optimum ray path containing the point of maximum transmitting antenna gain, expressed as a negative value in dB.

SPACECRAFT (SIC) TRANSMITTING DATA CHANNEL PARAMETERS

(56) *INFORMATION BIT RATE*: The basic telemetry data rate generated by the flight data system, prior to any encoding or spectrum spreading procedures, for transmission to the receiving earth station, expressed in kilo-bits per second (kb/s).

(57) *SUBCARRIER FREQUENCY*: The unmodulated Telemetry subcarrier's frequency, expressed as a positive value in kilo-Hertz (kHz).

(58) *SUBCARRlER WAVEFORM*: The waveform of the Telemetry subcarrier, either sine wave or square wave, expressed as Sin or Sq.

(59) *RF MODULATION INDEX*: The angle by which the rf carrier is phase shifted, with respect to the unmodulated rf carrier, as a result of the data on Telemetry channel of the modulator, expressed in radians peak.

4.13 ANNEX TO RECOMMENDATION (Continued)

SPACECRAFT (S/C) TRANSMITTING RANGING CHANNEL PARAMETERS

(60) *SIMULTANEOUS WITH DATA*: A statement showing whether or not the computed performance is based upon simultaneous ranging and telemetry operations (e.g., Yes or No).

(61) *MOD INDEX TONE / CODE*: The angle by which the rf carrier is phase shifted, with respect to the unmodulated rf carrier, as a result of the ranging Tones / Codes modulation, expressed in radians peak (Rad-pk).

SPACE-TO-EARTH PATH PARAMETERS

(62) *TOPOCENTRIC RANGE*: The distance, measured along a ray path, between the spacecraft antenna's radiation point and ground station antenna's reference point, expressed in kilometers (km).

(63) *ATMOSPHERIC ATTENUATION*: The reduction in signal power at the receiving antenna, considering such factors as the earth station's antenna elevation angle, weather, and geographical location, which results from absorption, reflection, and scattering of the rf signal as it passes through the Earth's atmosphere, expressed as a negative value in dB.

(64) *IONOSPHERIC LOSS*: The reduction in signal power at the receiving antenna, considering such factors as the earth station's elevation angle and communication's frequency, resulting from the dispersive loss in radiated signal as it passes through the Ionosphere of the Earth and/or other bodies, expressed as a negative value in dB.

(65) *ANTENNA ELEVATION ANGLE*: The angle between a ray, representing the boresight of the earth-station's antenna beam pattern, and a locally horizontal line, when both ray and line are contained in a vertical plane which also contains the center of the earth, expressed in degrees (Deg).

EARTH STATION (E/S) RECEIVING RF CARRIER CHANNEL PARAMETERS

(66) *ANT GAIN*: Same definition as (3) above except that it is applicable to the earth station's receiving frequency. See second paragraph of (3) above to access earth station data base.

(67) *POLARIZATION LOSS*: The reduction in transferred signal power between transmitting and receiving stations resulting from differences in the radiated and received polarization patterns between the two antennas, expressed as a negative value in dB.

(68) *ANTENNA POINTING LOSS*: Same definition as (5) above except that it is applicable to the pointing error of the earth station's receiving antenna.

(69) *ANTENNA CIRCUIT LOSS*: The attenuation in rf power occurring between the point of electromagnetic radiation on the earth station's antenna and the input terminals of the low noise amplifier, expressed as a negative value in dB.

4.1.3 ANNEX TO RECOMMENDATION (Continued)

(70) *TOTAL NOISE TEMPERATURE*: The sum of the following noise temperature components (a) + (b) + (c) + (d), expressed in dBK. ***This sum is a computed entry and is <u>not</u> supplied by the user.***

(a) *Rcvr Operating Temp*: Overall Noise Temperature (CCIR/Rec 573-1): "For an antenna, or a receiving system including the antenna, the value to which the temperature of the resistive component of the source impedance should be brought, if it were the only source of noise, to cause the noise power at the output of the receiver to be the same as in real case."

In the Link Design Control Table, this parameter represents a receiving system reference temperature, at the received frequency, which excludes all contributions enumerated in (b), and (c), below, expressed in Kelvin. The reference temperature is measured at the input to the low-noise amplifier with the antenna viewing a cold sky background and which includes contributions from the: 1) cosmic background; 2) low noise amplifier and/or receiver; 3) circuit losses before the low noise amplifier and/or receiver.

(b) *Feed Through Noise*: The increase in the receiver's operating temperature resulting from a portion of the transmitted signal leaking into the receiver's low-noise amplifier, expressed in Kelvin (K).

(c) *Hot Body Noise*: The predicted increase from the reference temperature (Tr), resulting from the receiving antenna being directed toward a body having a temperature greater than that of the cold sky reference, expressed in Kelvin (K).

(d) *Weather Temp Increase*: The predicted increase from the reference temperature, resulting from the selected ground station weather model, and which excludes contributions from atmospheric attenuation (63), Ionospheric loss (64), and from (b) and (c) above, expressed as a positive value in Kelvin.

(71) *THRESHOLD LOOP NOISE BW*: The total (2-sided) bandwidth of the rf carrier phase-locked-loop, measured at carrier threshold, expressed in Hz.

(72) *REQD THRSHLD SNR IN 2 B_{LO}*: The ratio of received carrier power in 2 B_{LO} to the noise power density required to maintain receiver lock at threshold which has been defined to be + 10 dB, expressed in dB.

4.1.3 ANNEX TO RECOMMENDATION (Continued)

EARTH STATION (E/S) RECEIVING DATA CHANNEL PARAMETERS

(73) *PHASE JITTER LOSS*: The loss in symbol detection efficiency resulting from phase noise on the received rf carrier, which produces a non-orthogonal, noisy phase relationship between the demodulator's reference and the rf carrier to be demodulated, plus losses from the partial tracking of the modulated symbols by the rf carrier phase locked loop, expressed as a negative value in dB.

(74) *DEMOD / DETECTOR LOSS*: The loss in data demodulation and detection efficiency resulting from phase noise on the demodulated subcarrier, if any, which produces a non-orthogonal, noisy phase relationship between the demodulator's reference and the subcarrier to be demodulated, plus losses from the partial tracking of the data bits by the subcarrier loop, plus losses due to timing errors in the symbol synchronizer's tracking loop, plus losses from non-linearities in the demodulator, which reduce the device's efficiency, expressed as a negative value in dB.

(75) *WAVEFORM DISTORTION LOSS*: The loss in the recovered data signal power, which results from distortion in the modulated signal's (subcarrier and data) waveform, which has been introduced by non-linearities in the data channel or medium, expressed as a negative value in dB.

(76) *MAX RNG INTERFER TO DATA*: The ratio of the ranging modulation's maximum spectral power level, lying within the data spectrum bandwidth [*data spectrum bandwidth equals the data symbol rate in Hz*], to the total ranging power level, expressed as a negative value in dB.

(77) *REQD DATA E_b / N_o*: The energy per data bit divided by the noise spectral density which is required to obtain the stated Bit Error Rate, considering the improvement due to coding, expressed in dB.

EARTH STATION (E/S) RECEIVING RANGING CHANNEL PARAMETERS

(78) *RANGING DEMODULATOR LOSS*: The loss in ranging demodulation and detection efficiency resulting from phase noise on the demodulated subcarrier, which produces a non-orthogonal, noisy phase relationship between the demodulator's reference and the i.f. carrier to be demodulated, plus losses from non-linearities in the demodulator, which reduce the device's efficiency, expressed as a negative value in dB.

(79) *REQD TONE/CODE 1 PWR/N_o*: The magnitude of range tone/code 1 ST/N_o required to achieve the desired Range accuracy, expressed as a positive or negative value in dB-Hz.

(80) *REQD TONE/CODE 2 PWR/N_o*: The magnitude of range tone/code 2 ST/N_o required to achieve the desired probability of error in the ranging measurement, expressed as a positive or negative value in dB-Hz.

4.1.3 ANNEX TO RECOMMENDATION (Continued)

LINK COMPUTATIONS FOR EARTH-TO-SPACE LINK

EARTH STATION (E/S) TRANSMITTING RF CARRIER CHANNEL PERFORMANCE

(101) *TRANSMITTER POWER*: That power actually produced at the transmitter power amplifier's output terminals, expressed as a positive or negative value in dBW (10 Log_{10} [Watts]).

(102) *TRANSMIT ANT GAIN [Effect]*: The computed antenna gain found by subtracting the Antenna Circuit Loss and Antenna Pointing Loss from the Antenna Gain [(3)]-[(4)+(5)], expressed as a positive or negative value in dBi.

(103) *TRANSMITTING E.I.R.P.*: The computed effective isotopically radiated power found by adding Transmitter Power and Effective Antenna Gain [(101) + (102)], expressed as a positive or negative value in dBW.

(104) *TRANS CARRIER POWER*: The computed portion of the total transmitted power remaining in the rf carrier channel after subtracting the power in the sidebands due to the modulating signals, expressed as a positive or negative value in dBW.

(105) *TRANS CARRIER POWER/P_T*: The power computed in (104) above, divided by the total earth station transmitted power, expressed as a negative value in dB.

EARTH STATION (E/S) TRANSMITTING DATA CHANNEL PERFORMANCE

(106) *TRANS CH 1 DATA POWER*: The computed power in the rf carrier's data sidebands resulting from the modulating signal on data Channel 1, expressed as a positive or negative value in dBW.

(107) *TRANS CH 1 DATA POWER/P_T*: The Channel 1 data power computed in (106) above, divided by the total earth station transmitted power, expressed as a negative value in dB.

(108) *TRANS CH 2 DATA POWER*: The computed power in the rf carrier's data sidebands resulting from the modulating signal on data Channel 2, expressed as a positive or negative value in dBW.

(109) *TRANS CH 2 DATA POWER/P_T*: The Channel 2 data power computed in (108) above, divided by the total earth station transmitted power, expressed as a negative value in dB.

EARTH STATION (E/S) TRANSMITTING RANGING CHANNEL PERFORMANCE

(110) *TONE - CODE 1 POWER*: The computed power in the rf carrier's ranging sidebands resulting from either Tone 1 (major) or Code 1 modulation, expressed as a positive or negative value in dBW.

(111) *TONE - CODE 1 POWER/P_T*: The Tone or Code 1 power computed in (110) above, divided by the total earth station transmitted power, expressed as a negative value in dB.

4.1.3 ANNEX TO RECOMMENDATION (Continued)

(112) *TONE - CODE 2 POWER*: The computed power in the rf carrier's ranging sidebands resulting from either Tone 2 (minor) or Code 2 modulation, expressed as a positive or negative value in dBW.

(113) *TONE - CODE 2 POWER/P_T*: The Tone or Code 2 power computed in (112) above, divided by the total earth station transmitted power, expressed as a negative value in dB.

EARTH-TO-SPACE PATH PERFORMANCE

(114) *FREE SPACE LOSS*: The computed loss resulting from the spreading of the signal as it propagates from transmitting to receiving stations, expressed as a negative value in dB.

(115) *ATMOSPHERIC ATTENUATION*: The reduction in signal power at the receiving antenna, considering such factors as the earth station's antenna elevation angle, weather, and geographical location, which results from absorption, reflection, and scattering of the rf signal as it passes through the Earth's atmosphere, placed on this page for reference purposes, expressed as a negative value in dB.

(116) *IONOSPHERIC LOSS*: The reduction in signal power at the receiving antenna, considering such factors as the earth station's elevation angle and communication's frequency, resulting from the dispersive loss in radiated signal as it passes through the Ionosphere of the Earth and/or other bodies, placed on this page for reference purposes, expressed as a negative value in dB.

SPACECRAFT (S/C) RECEIVING RF CARRIER CHANNEL PERFORMANCE

(117) *RECEIVING ANT GAIN [Effect]*: The computed antenna gain found by subtracting the Polarization Loss, Antenna Pointing Loss, and Antenna Circuit Loss from the Antenna Gain (17)-[(18) + (19) + (20)], expressed as a positive or negative value in dBi.

(118) *NOISE SPECTRAL DENSITY*: The computed noise, generally resulting from the receiver's low noise amplifier, in a 1 Hz bandwidth, expressed in dBW/Hz.

(119) *THRESHOLD LOOP BW 2 B_{LO}*: Same definition as (24) above, placed on this page for reference purposes.

(120) *RCVD CARRIER POWER*: The computed carrier power in the receiver's phase locked loop bandwidth of 2 B_{LO}, expressed as a positive or negative value in dBW.

(121) *CARRIER PERFORMANCE MARGIN*: The computed excess in rf carrier signal over +10 dB SNR in the phase-locked-loop, which is defined to be carrier threshold, expressed in dB.

4.1.3 ANNEX TO RECOMMENDATION (Continued)

SPACECRAFT (S/C) RECEIVING DATA CHANNEL PERFORMANCE

(122) *CH 1 DATA LOSS DUE TO RNG*: The computed loss in data channel's performance resulting from the presence of a simultaneous ranging signal on the earth-to-space link, expressed in dB.

(123) *RCVD CH 1* E_b / N_o: The computed received energy per bit in Data Channel 1 divided by the noise spectral density, expressed in dB.

(124) *REQD CH 1* E_b / N_o: The computed energy per bit divided by the noise spectral density (E_b / N_o) found by adding the Phase Jitter Loss, Demod/Detector Loss, Waveform Distortion Loss, and Maximum Ranging Interference to Data to the Required Data E_b / N_o [(29)] + [(25) + (26) + (27) + (28)], expressed in dB.

(125) *CH 1 DATA PERFORM MARGIN*: The computed excess of Channel 1 received E_b/N_o over the required E_b / N_o, [(123)-(124)], expressed in dB.

(126) *CH 2 DATA LOSS DUE TO RNG*: Same definition as (122) above except that it is applicable to data channel 2.

(127) *RCVD CH 2* E_b / N_o: Same definition as (123) above except that it is applicable to data channel 2.

(128) *REQD CH 2* E_b / N_o: Same definition as (124) above except that it is applicable to data channel 2.

(129) *CH 2 DATA PERFORM MARGIN*: The computed excess of Channel 2 received E_b / N_o over the required E_b / N_o [(127)-(128)], expressed in dB.

SPACECRAFT (S/C) RECEIVING RANGING CHANNEL PERFORMANCE

(130) *RCVD CODE 1 POWER/*N_o: The computed received power (P_R) in the ranging Tone 1 (major) or Code 1 divided by the noise spectral density, expressed as a positive or negative value in dB-Hz.

(131) *RCVD CODE 2 POWER/*N_o: Same definition as (130) above except that it is applicable to Tone or Code 2.

(132) *RCVD TOTAL RNG POWER/*N_o: The computed total received power in all ranging Tones or Codes, if several are present simultaneously, or Tone/Code 1 if Tones or Codes are transmitted sequentially, divided by the noise spectral density, expressed as a positive or negative value in dB-Hz.

(133) *RANGING MARGIN*: The computed excess of received total ranging power over the required ranging power, expressed in dB.

4.1.3 ANNEX TO RECOMMENDATION (Continued)

LINK COMPUTATIONS FOR SPACE-TO-EARTH LINK

SPACECRAFT (S/C) TRANSMITTING RF CARRIER CHANNEL PERFORMANCE

(151) *TRANSMITTER POWER*: That power actually produced at the transmitter power amplifier's output terminals, expressed as a positive or negative value in dBW (10 Log_{10} [Watts]).

(152) *TRANSMIT ANT GAIN [Effect]*: The computed antenna gain found by subtracting the Antenna Circuit Loss and Antenna Pointing Loss from the Antenna Gain (53)-[(54) + (55)], expressed as a positive or negative value in dBi.

(153) *TRANSMITTING E.I.R.P.*: The computed effective isotopically radiated power found by adding Transmitter Power and Effective Antenna Gain [(151) + (152)], expressed as a positive or negative value in dBW.

(154) *TRANS CARRIER POWER*: The computed portion of the total transmitted power remaining in the rf carrier channel after subtracting the power in the sidebands due to the modulating signals, expressed as a positive or negative value in dBW.

(155) *TRANS CARRIER POWER/P_T:* The power computed in (154) above, divided by the total spacecraft transmitted power, expressed as a negative value in dB.

SPACECRAFT (S/C) TRANSMITTING DATA CHANNEL PERFORMANCE

(156) *TRANS CH 1 DATA POWER*: The computed power in the rf carrier's data sidebands resulting from the modulating signal on data Channel 1, expressed as a positive or negative value in dBW.

(157) *TRANS CH 1 DATA POWER/P_T*: The Channel 1 data power computed in (156) above, divided by the total spacecraft transmitted power, expressed as a negative value in dB.

(158) *TRANS CH 2 DATA POWER*: The computed power in the rf carrier's data sidebands resulting from the modulating signal on data Channel 2, expressed as a positive or negative value in dBW.

(159) *TRANS CH 2 DATA POWER/P_T*: The Channel 2 data power computed in (158) above, divided by the total spacecraft transmitted power, expressed as a negative value in dB.

SPACECRAFT (S/C) TRANSMITTING RANGING CHANNEL PERFORMANCE

(160) *TONE - CODE 1 POWER*: The computed power in the rf carrier's ranging sidebands resulting from either Tone 1 (major) or Code 1 modulation, expressed as a positive or negative value in dBW.

(161) *TONE - CODE 1 POWER/P_T*: The Tone or Code 1 power computed in (160) above, divided by the total earth station transmitted power, expressed as a negative value in dB.

4.1.3 ANNEX TO RECOMMENDATION (Continued)

(162) *TONE - CODE 2 POWER*: The computed power in the rf carrier's ranging sidebands resulting from either Tone 2 (major) or Code 2 modulation, expressed as a positive or negative value in dBW.

(163) *TONE - CODE 2 POWER/*P_T: The Tone or Code 2 power computed in (162) above, divided by the total spacecraft transmitted power, expressed as a negative value in dB.

SPACE-TO-EARTH PATH PERFORMANCE

(164) *FREE SPACE LOSS*: The computed loss resulting from the spreading of the signal as it propagates from transmitting to receiving station, expressed as a negative value in dB.

(165) *ATMOSPHERIC ATTENUATION*: The reduction in signal power at the receiving antenna, considering such factors as the earth station's antenna elevation angle, weather, and geographical location, which results from absorption, reflection, and scattering of the rf signal as it passes through the Earth's atmosphere, placed on this page for reference purposes, expressed as a negative value in dB.

(166) *IONOSPHERIC LOSS*: The reduction in signal power at the receiving antenna, considering such factors as the earth station's elevation angle and communication's frequency, resulting from the dispersive loss in radiated signal as it passes through the Ionosphere of the Earth and/or other bodies, placed on this page for reference purposes, expressed as a negative value in dB.

EARTH STATION (E/S) RECEIVING RF CARRIER CHANNEL PERFORMANCE

(167) *RECEIVING ANT GAIN [Effect]*: The computed antenna gain found by subtracting the Polarization Loss, Antenna Pointing Loss, and Antenna Circuit Loss from the Antenna Gain (66)-[(67)+(68)+(69)], expressed as a positive or negative value in dBi.

(168) *NOISE SPECTRAL DENSITY*: The computed noise, generally resulting from the receiver's low noise amplifier, in a 1 Hz bandwidth, expressed in dBW/Hz.

(169) *THRESHOLD LOOP BW, 2* B_{LO}: Same definition as (71) above, placed on this page for reference purposes.

(170) *RCVD CARRIER POWER*: The computed carrier power in the receiver's phase locked loop bandwidth of 2 B_{LO}, expressed in dBW.

(171) *CARRIER PERFORMANCE MARGIN*: The computed excess in rf carrier signal over +10 dB SNR in the phase-locked-loop, which is defined to be carrier threshold, expressed in dB.

4.1.3 ANNEX TO RECOMMENDATION (Continued)

EARTH STATION (E/S) RECEIVING DATA CHANNEL PERFORMANCE

(172) *CH 1 DATA LOSS DUE TO RNG*: The computed loss in data channel's performance resulting from the presence of a simultaneous ranging signal on the space-to-earth link, expressed in dB.

(173) *RCVD CH 1* E_b / N_o: The computed received energy per bit in Data Channel 1 divided by the noise spectral density, expressed in dB.

(174) *REQD CH 1* E_b / N_o: The computed energy per bit divided by the noise spectral density (E_b / N_o) found by adding the Phase Jitter Loss, Demod/Detector Loss, Waveform Distortion Loss, and Maximum Ranging Interference to Data to the Required Data E_b / N_o [(77)]+[(73)+(74)+(75)+(76)], [includes the improvement due to coding], expressed in dB.

(175) *CH 1 DATA PERFORM MARGIN*: The computed excess of Channel 1 received E_b / N_o over the required E_b / N_o [(173)-(174)], expressed in dB.

(176) *CH 2 DATA LOSS DUE TO RNG*: Same definition as (172) above except that it is applicable to data channel 2.

(177) *RCVD CH 2* E_b / N_o: Same definition as (173) above except that it is applicable to data channel 2.

(178) *REQD CH 2* E_b / N_o: Same definition as (174) above except that it is applicable to data channel 2.

(179) *CH 2 DATA PERFORM MARGIN*: The computed excess of Channel 2 received E_b / N_o over the required E_b / N_o, [(177)-(178)], expressed in dB.

EARTH STATION (E/S) RECEIVING RANGING CHANNEL PERFORMANCE

(180) *RCVD CODE 1 POWER/*N_o: The computed received power (P_R) in the ranging Tone 1 (major) or Code 1 divided by the noise spectral density, expressed as a positive or negative value in dB-Hz.

(181) *RCVD CODE 2 POWER/*N_o: Same definition as (180) above except that it is applicable to Tone or Code 2.

(182) *RCVD TOTAL RNG POWER/*N_o: The computed total received power in all ranging Tones or Codes, if several are present simultaneously, or Tone/Code 1 if Tones or Codes are transmitted sequentially, divided by the noise spectral density, expressed as a positive or negative value in dB-Hz.

(183) *RANGING MARGIN*: The computed excess of received total ranging power over the required ranging power, expressed in dB.

5.0 TERMINOLOGY AND GLOSSARY

Section 5 is included to assist the reader in interpreting the Recommendations found in Sections 2, 3, and 4 of this document. It does so by providing an explanation of key words, terms, phrases, abbreviations, and acronyms used in these Recommendations. Presently, there are two subsections:

5.1 *Terminology* 5.2 *Glossary*

Section 5.1, Terminology, defines specific words, terms, and phrases which have special, but uniform, meanings throughout the text. Additionally, this section also includes quantitative values for some terms which are intended to assist the reader in interpreting the Recommendations.

Section 5.2 contains the full name for the abbreviations and acronyms used throughout this document. If a reader is uncertain as to the meaning any abbreviation or acronym, this Section should be consulted. Here, entries are arranged alphabetically.

5.1 TERMINOLOGY

Auto track	A system which causes earth station's antenna to automatically follow [track] a moving spacecraft.
Bit Rate	The baseband data rate exclusive of coding for either error correction or spectrum shaping purposes.
Category A Missions	Those missions whose altitude above the earth is less than, or equal to, 2 x 10^6 km.
Category B Missions	Those missions whose altitude above the earth is greater than 2 x 10^6 km.
Dibit	A group of two bits in 4-phase modulation, each possible *dibit* is encoded in the form of one of four unique phase shifts of the RF carrier.
Loop Bandwidth	The resultant phase locked bandwidth when the signal-to-noise ratio in the phase locked loop is 10 dB.
Loop Threshold	That signal level producing a signal-to-noise ratio of 10 dB in the phase locked loop's bandwidth.
Libration Point	*A point of equal potential gravitational fields between two or more large bodies such as the Sun and the Earth*
Link Design Control Table	A set of tables used to display the operating parameters of a telecommunications link and to calculate the expected performance of that link.
Link and Weather Not Combined	With a Link Design Control Table, calculations are made assuming clear and dry weather conditions. Thereafter, the values obtained under such ideal conditions are adjusted using a correction factor representing the loss due to weather effects.
Modulo-2 Addition	Also called an "*exclusive or*", this term refers to the manner in which a pair of bits are added such that like bits result in a 0 and unlike bits produce a 1.
Occupied Bandwidth	(ITU/RR/147): "The width of a frequency band such that, below the lower and above the upper frequency limits, the mean powers emitted are each equal to a specified percentage ß/2 of the total mean power of a given emission." [Unless otherwise specified by the CCIR for the appropriate class of emission, the value of ß/2 should be taken as 0.5%."]
Radiocommunication Service	(ITU/RR/RR1-3.1) "A Service... involving the transmission, emission and/or reception of radio waves for specific telecommunication purposes."

5.1 TERMINOLOGY (Continued)

Ranging Measurement	A process for establishing, usually by a time delay measurement, the one-way distance between an earth station and a spacecraft.
Symbol Rate	The baseband bit rate following error correction coding but excluding any spectrum modification encoding.

5.2 GLOSSARY OF TERMS

ACQ or Acq	Acquisition
AGC	Automatic Gain Control
AM	Amplitude Modulation
BER	Bit Error Rate
Bi-ϕ-L	Bi-Phase-Level modulation
Bi-ϕ-M	Bi-Phase-Mark modulation
Bi-ϕ-S	Bi-Phase-Space modulation
B_{LO}	Phase Locked Loop Bandwidth
BNSC	British National Space Centre
bps or b/s	Bits Per Second
BW	Bandwidth
Cat	Category
Category A Missions	Those missions whose altitude above the Earth is less than, or equal to, 2 x 10^6 km.
Category B Missions	Those missions whose altitude above the Earth is greater than 2 x 10^6 km.
CCIR	International Radio Consultative Committee
CCSDS	Consultative Committee for Space Data Systems
Cmd	Telecommand
CNES	Centre National D'Etudes Spatiales
COHER or Coh	Coherent
CRL	Communications Research Laboratory
CSA	Canadian Space Agency
dB	Decibel(s)
dBi	Decibel(s) relative to an isotropically radiated signal
dB/K	Decibel(s) per degree Kelvin
dBm	Decibel(s) relative to one milliwatt
dBW	Decibel(s) relative to one Watt
DCT	Design Control Table [Link]
deg	Degree
DLR	Deutsche Forschungsanstalt fuer Luft-und Raumfahrt e. V.
DNRZ	Differential Non-Return to Zero

5.2 GLOSSARY OF TERMS (Continued)

DOC/CRC	Department of Communications, Communications Research Centre
DRVID	Differenced Range vs. Integrated Doppler
E_b	Energy per data bit
E_b / N_o	Energy per data bit to Noise ratio in a 1 Hz bandwidth
EES	Earth Exploration Service
EIRP	Equivalent Isotropically Radiated Power
ELEV	Elevation
E/S	Earth-to-Space
ESA	European Space Agency
exp	Exponent
f or Freq	Frequency
f_c	RF carrier frequency
f_d	Doppler frequency shift
f_{sc}	Subcarrier frequency
FM	Frequency Modulation
FN or Fn	Footnote
FSK	Frequency Shift Keying
GHz	Gigahertz
GND	Ground
GPS	Global Positioning System
G/T	Antenna gain divided by the receiving system's noise temperature in degrees Kelvin (usually expressed in dB).
h	Hours
Hz	Hertz
IEEE	Institute of Electrical and Electronic Engineers
IFRB	International Frequency Registration Board
INPE	Instituto De Pesquisas Espaciais
ISAS	Institute of Space and Astronautical Science
ISRO	Indian Space Research Organization
ITU	International Telecommunication Union
ITU/RR	International Telecommunication Union Radio Regulations
k	Kilo (thousands)

5.2 GLOSSARY OF TERMS (Continued)

K	Degrees Kelvin
kb/s	Kilobits Per Second
kHz	Kilohertz
km	Kilometers
Ku	Ku-band (approximately 13 to 15 gigahertz)
LCP	Left Circular Polarization
LIM or Lim	Limitation(s)
LIN or Lin	Linear
L.O. or LO	Local Oscillator
M	Mega (million)
m	Meter(s)
MAX or Max	Maximum
MHz	Megahertz
MIN or Min	Minimum
Mod	Modulation
n	Nano
ns	Nanosecond(s)
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NOAA	National Oceanic and Atmospheric Administration
NRZ	Non-Return to Zero
NRZ-L	Non-Return to Zero-Level
NRZ-M	Non-Return to Zero-Mark
NRZ-S	Non-Return to Zero-Space
P_c	Carrier power
PCM	Pulse Code Modulation
PDF	Probability Density Function
PFD	Power Flux Density
Pk or pk	Peak
P_{LL}	Phase Locked Loop
PM	Phase Modulation

5.2 GLOSSARY OF TERMS (Continued)

PN	Pseudo Noise
ppm	Parts Per Million
PRN	Pseudo Random Noise
PSK	Phase Shift Keying
PWR	Power
QPSK	Quadra-Phase Shift Keying [modulation]
OQPSK	Offset Quadra-Phase Shift Keying [modulation]
r	Range
Rad	Radian
RCP	Right Circular Polarization
RCVR or Rcvr	Receiver
Rec	Receive
REF or Ref	Reference
regen.	regenerative
resid.	residual
RF	Radio Frequency
RFI	Radio Frequency Interference
RLIN	Rotatable Linear polarization
rms	Root Mean Square
Rng	Ranging
RSS	Root Sum Square
S/C	Spacecraft
s or sec	Second(s)
S/E	Space-to-Earth
SEP	Sun-Earth-Probe [angle]
seq	Sequential
SFDU	Standard Formatted Data Unit (CCSDS)
SFCG	Space Frequency Coordination Group
SIG or sig	Signal
Sim	Simultaneous
SNR	Signal-to-Noise Ratio

5.2 GLOSSARY OF TERMS (Continued)

SP	Split Phase
SP-L	Split Phase - Level
sps or s/s	Symbols Per Second
SSC	Swedish Space Corporation
STA	Station
STAB	Stability
SUBCARR	Subcarrier
SYM or sym	Symbol
TBD	To Be Determined
TDRSS	Tracking and Data Relay Satellite System
Tlm	Telemetry
Trans or Tr	Transmit
TTC	Tracking, Telemetry, and Command
UTC	Universal Time Coordinated
VLBI	Very Long Baseline Interferometry
w/m^2	Watts per square Meter
X-band	Approximately 8000 megahertz
XMIT or Xmit	Transmit
yr	Year
Δ	Delta (change or variation)
ϕ	Phase
μ	Micro